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CLIMATE CHANGE MITIGATION IN THE ENERGY AND FORESTRY SECTORS OF DEVELOPING COUNTRIES*

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ABSTRACT

The continued accumulation of greenhouse gases in the atmosphere is expected to severely impact the earth's natural resources and agriculture. Greenhouse gas emissions from the developing world are rising faster than those from other countries, and many studies have noted that it would not be possible to stabilize climate change without reducing the growth of these emissions. Can this be achieved without affecting economic growth and social fabric in these countries? Mitigation studies indicate that if energy efficiency and forestry options are implemented judiciously, emissions can be reduced at a negative cost without affecting economic growth. The studies also suggest that this would increase significantly the worldwide demand for natural gas and renewable technologies. Country studies show that the aggregate mitigation potential in the forestry sector is higher, and the costs per tonne of carbon are lower, than reported earlier by global studies. Barriers to the implementation of energy and forestry options need to be explicitly taken into consideration because these may change the priority of options and the choice of policy measures.

CONTENTS

1. INTRODUCTION

The earth's fragile atmosphere is changing with the continuing release of greenhouse gases (GHGs) around the world. At increasing atmospheric concentrations, GHGs are projected to raise the average world temperature, lead to a rise in sea level, and change seasonal and geographic precipitation patterns (1). These changes are expected to severely impact agriculture, ecosystems, water resources, coastal areas, and human health. Concern about such impacts led more than 160 nations to ratify the United Nations Framework Convention on Climate Change (UNFCCC), which was adopted in Rio de Janeiro in 1992 (2). The nations include those from the Organization for Economic Cooperation and Development (OECD), which along with Russia and the Eastern European countries are known as the Annex I countries, and a group comprised mostly of developing countries, referred to as the non–Annex I countries.

Developing countries today have lower income per capita and use fuel less efficiently than industrialized countries do. This less efficient use of fuels stems from both a lack of state-of-the-art technology and proportionally higher use of coal and biomass, which produce more of the GHG carbon dioxide (CO_2) per unit of energy than do petroleum products and natural gas. In addition, developing countries are net emitters of GHGs from the burning of forests for land clearing and the burning of nonrenewable biomass for cooking and other uses (3). Commensurate with the high economic and high population growth in developing countries, their GHG emissions are expected to increase rapidly, to match those from industrialized countries around 2018 (3a).

There is much debate about the extent of each country's responsibility for stabilizing global climate change. The 1997 meeting in Kyoto, Japan, of the Third Conference of the Parties to the UNFCCC (3b) illustrated the sharp division between the 130 or so developing countries on the one hand and the industrialized countries on the other. The Annex I countries (which, except Belarus and Turkey, are listed as Annex B in the Kyoto Protocol) agreed to cap their emissions averaged over the period of years from 2008 to 2012 at levels ranging from 7% below to 10% above that of their 1990 levels. The developing countries, often referred to as the "G77+China," resisted commitments to limit the growth of their GHG emissions on the grounds that these emissions have thus far been generated mainly by industrialized countries. Why, developing nations ask, should they assume responsibility for a problem they did not cause? The industrialized countries do not contest this position but point out that many emerging low-cost opportunities for reducing GHG emissions are found in developing countries. Can these opportunities be secured without affecting the economic growth and social fabric in these countries, particularly in view of their perennial shortage of capital for investment in new technologies and hard currency for the purchase of imported goods?

Climate change mitigation analysis, which is the process of projecting future GHG emissions growth and evaluating strategies for reducing this growth, is a valuable tool for addressing this question and for resolving the debate between industrialized and developing nations on the extent to which developing countries could reduce their emissions. Using mitigation analysis, developing countries can discover how far and how fast they can go in reducing GHG emissions within their borders without jeopardizing, and even enhancing, their aspirations for sustainable development. Options for reducing GHG emissions growth, such as more efficient motors and appliances or increased use of wind and solar energy, are compatible with the policies and programs currently being implemented by developing countries in their pursuit of greater economic growth; in fact, most of these countries are already pursuing options to slow the growth of GHG emissions for good reasons other than the need to prevent global warming. (The variety of options being pursued is discussed in Section 3.)

GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), nitrogen oxides (NO_x), and chlorofluorocarbons. Of these, carbon dioxide and methane contribute the most to global warming. The Kyoto protocol addresses the measurement and control of six GHGs: CO_2, CH_4, N_2O, and three chlorofluorocarbons (CFCs)—hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). Although there are natural sources of the first three gases, CFCs are produced only by human activity. All the other GHGs have greater effect per kilogram than does CO_2 on global climate. This capacity to affect climate is measured as global warming potential

(GWP), which combines the capacity of a GHG to absorb infrared radiation and its residence time in the atmosphere and then expresses the combination relative to CO_2. For example, the GWP for methane (using a 100-year time horizon) is 21; in other words, 1 kg of methane will, over a 100-year period, have a radiative forcing effect 21 times greater than 1 kg of CO_2. CO_2 by definition has a GWP of 1; although this is lower than the GWP of other GHGs, we focus on the mitigation options to control CO_2 because the volume of CO_2 released is much larger than that of other gases and it accounts for over half of radiative forcing (4).

The primary source of CO_2 emissions is burning of fossil fuels and biomass. Additional CO_2 is released through industrial processes, such as the production of cement. The primary sources of methane are paddy fields, cattle and other animals, landfills, and waste streams. A major source of N_2O is from the use of fertilizers for crop production. CFCs are released during the manufacture of freon substitutes and insulation. NO_x comes primarily from fuel combustion, during which nitrogen and oxygen combine at high temperature. The GWP of NO_x has not yet been estimated.

The sources of GHG emissions may be characterized broadly into energy and non-energy sectors. The energy sector comprises the energy end uses in industry, transportation, households, commercial establishments, and agriculture, as well as the supply and transformation of energy. The non-energy sector includes forestry, agriculture, and waste management. Most work on mitigation options to date has studied CO_2 emissions and sequestration in the energy and forestry sectors. We therefore focus on CO_2 mitigation for these two sectors.

2. CLIMATE CHANGE MITIGATION STUDIES: BACKGROUND

Climate change country studies may be categorized into three types: (*a*) inventory-of-GHG-emissions studies; (*b*) mitigation studies; and (*c*) vulnerability and adaptation (V&A) studies. Inventory studies quantify, for a given year, the level of GHG emissions and sequestration of carbon from all sources in a country. Mitigation studies project future GHG emissions and the economic and other implications of limiting their growth. V&A studies estimate the impacts of climate change on a region or country and evaluate strategies to reduce or adapt to these impacts. This article focuses on mitigation studies in developing countries.

A handful of major multi-country efforts have studied opportunities for climate change mitigation in the developing world since 1989. A unique feature of most of the studies discussed below is that the work was carried out by institutions within each country rather than by consultants or experts from abroad.

Institutions in industrialized countries provided technical assistance and training on methods and tools for analysis. The results thus present perspectives of analysts from the country being analyzed.

Precursors to today's mitigation studies were led by research groups; the first effort was coordinated by the Lawrence Berkeley National Laboratory (LBNL) of the United States (5). The main focus of these studies was the preparation of long-term (through the year 2025) energy and carbon scenarios using a detailed end-use approach for 12 countries or groups of countries. A more ambitious effort, which included the estimation of costs of mitigation options, was initiated by the United Nations Environment Programme's Collaborating Centre for Energy and Environment (UNEP/CCEE) at the Riso National Laboratory in Denmark (6, 6a). In parallel, the Asian Development Bank (ADB) completed a broad climate change study that evaluated mitigation as well as vulnerability and adaptation options in several Asian countries (7).

A parallel research effort was coordinated by LBNL on mitigation options in the forestry sector. Its main focus was on developing methods to estimate carbon emissions from land-use change and to evaluate mitigation options to reduce net emissions; seven tropical countries with significant deforestation problems were studied along with China (8, 9).

In the early 1990s, governments in several industrialized countries, notably the United States, Germany, The Netherlands, and Denmark, initiated climate change studies in collaboration with developing countries. The United States undertook the US Country Studies Program (CSP), in which 12 US government agencies participate, to support climate change studies in 56 developing and transitional-economy countries in order to assist them in meeting their reporting requirements to the UNFCCC (10). A unique feature of the German and Danish efforts is their attention to regional mitigation options that may be pursued jointly by neighboring countries, such as the use of hydro power across southern Africa. Together, the bilateral efforts have spent more than US $50 million on country studies, with the largest contribution from the United States, about $35 million. Two other multi-country efforts supported by the Global Environment Facility (GEF) are also under way. One, administered by United Nations Development Programme (UNDP)/ADB, focuses on 12 Asian countries and is called the Asia Least-Cost Greenhouse Gas Abatement Study (ALGAS); the other is administered by UNEP/CCEE and involves eight countries worldwide.

2.1 *Mitigation Studies Methodology*

A mitigation assessment prioritizes, for a given situation, technologies and practices that combat climate change by reducing GHG emissions or sequestering carbon. Options are generally prioritized by cost and occasionally by other criteria, such as ancillary social benefits. Conducting a mitigation assessment requires defining (*a*) the time frame for the proposed mitigation scenarios, (*b*) the geographic area and economic sectors to be targeted, (*c*) a range of results that will form part of a national action plan to reduce emissions growth, and (*d*) approaches appropriate to the data and expertise available in the country where mitigation is proposed. In keeping with UNFCCC, mitigation options should be consistent with a country's development objectives (11).

Two primarily different approaches, "bottom up" and "top down," have been used for mitigation analysis, particularly in the energy sector. The bottom-up approach is more engineering oriented and begins by characterizing technologies and processes, combinations of which are then evaluated to assess their aggregate GHG emissions and costs. To evaluate and rank options with respect to multiple criteria in addition to costs, some studies have used a "multicriteria approach." The top-down approach primarily evaluates the impact on a nation's gross domestic product (GDP) of policy instruments, such as changes in carbon or fuel taxes. These approaches are described in detail in their respective sections below. For the forestry sector (see Section 4), mitigation analysis typically involves assessing mitigation options in relation to the land available for emissions reduction or carbon sequestration and then exploring the costs and benefits of each option as well as the policies and other means to encourage implementation of options.

Most mitigation analyses include the development of a baseline scenario, a projection of potential future emissions growth in the absence of mitigation activities. Development of a baseline scenario involves both analysis and judgment about the future. As a consequence, baseline scenarios can be quite different and depend a great deal on an analyst's individual perspective, which may be guided by ulterior motives; for example, a country may deliberately increase its baseline emissions in order to show that extraordinary external resources are needed to reduce its future emissions.

3. ENERGY SECTOR

The energy sector contributes to the bulk of CO_2 emissions worldwide. A recent estimate places global CO_2 emissions from fossil-fuel combustion and natural gas flaring at 6.0 gigatonnes of carbon (GtC) in 1996 (12), up from 5.8 in 1990 (Table 1). The 1992 Intergovernmental Panel on Climate Change (IPCC) scenarios included in Table 1 show the emissions increasing to between 7 and 12.1 GtC by the year 2020, with a mid-range estimate of 9.91 GtC. The scenarios show a slowing of growth in the developing countries but a much higher growth rate in the Eastern Europe/former Soviet Union region, primarily because the decline in demand past 1990 was not anticipated when the scenarios

Table 1 Emissions of carbon dioxide[a] from fossil-fuel combustion and natural gas flaring

Country	1990[b]	1996[b] (AAGR)	Baseline projections (AAGR) (final year) (Ref.)
China	620	805 (4.4%)	1855 (3.5%) (2030)[c] 1671 (3.0%) (2020) (39)
India	155	232 (6.7%)	960 (5.9%) (2025) (39) 630 (4.2%) (2020) (42)
South Korea	61	113 (10.3%)	284 (3.8%) (2020) (42)
South Africa	81	96 (2.8%)	
Mexico	79	86 (1.4%)	134 (4.9%) (2005) (35) 164 (4.6%) (2010) (35)
Other developing countries	735	928 (3.9%)	
Total developing countries	1731	2260 (4.4%)	4050 (2.4%) (2020) (3a)
OECD	2804	2943 (0.8%)	3570 (0.8%) (2020) (3a)
East Europe/FSU	1296	833 (−7.4%)	2300 (4.2%) (2020) (3a)
Total world	5831	6036 (0.6%)	9910 (2.0%) (7000–12100)[d] (2020) (3a)

[a]In million tonnes of carbon. AAGR, Average annual growth rate; OECD, Organization for Economic Cooperation and Development; FSU, former Soviet Union.
[b]Reference 12.
[c]Reference 94.
[d]Intergovernmental Panel on Climate Change range of projections for scenarios 1992a through 1992f.

were made in 1992. Studies completed almost 10 years ago emphasized that it would not be possible to stabilize climate change without reducing the rapid growth of emissions from the developing countries (13); CO_2 emissions growth from developing countries between 1990 and 1996 supports this thesis, increasing at an annual rate of 4.4%, from 1.73 to 2.26 GtC. China, India, South Korea, South Africa, and Mexico rank as the second, sixth, tenth, thirteenth, and fourteenth largest contributors, respectively. Should China's emissions continue to increase at the 4.4% rate that was estimated for the period from 1990 to 1996, they would reach the 1996 US emissions level of 1466 million tonnes of carbon (MtC) by the year 2010. India's emissions, growing at 6.7% annually, will exceed the 1996 US figure by 2025. Future country-specific emissions scenarios reported in Table 1, however, project lower growth rates, which are discussed later in this section.

As noted in Section 2.1, mitigation studies use bottom-up, multi-criteria, and top-down approaches to evaluate energy-sector mitigation options. Each approach can use one or more mathematical models to aid in the evaluation of options. The structure of these models and the key variables that drive them differ. We present below the mitigation options, driving variables, and country study results separately for each of the three approaches.

3.1 *Results from GHG Mitigation Studies: Bottom-Up Approach*

The bottom-up approach provides a disaggregated picture of energy demand and supply and allows for estimation of potential gains in efficiency from specific technologies and/or the potential for substitution of less–carbon-intensive technologies. In this section, we (*a*) report on examples of technologies that can serve as mitigation options, (*b*) describe the bottom-up approach and the types of models that are being used to evaluate these options, (*c*) discuss key GDP and population growth assumptions and their implications for energy and carbon growth across scenarios reported for several countries, (*d*) present the costs of combinations of mitigation options by country, (*e*) show key features of the impacts on investment and foreign trade in some of the larger developing countries, and finally (*f*) report on the implications of mitigation options for worldwide fuel demand.

3.1.1 PRIMARY MITIGATION OPTIONS Mitigation options typically refer to technologies and processes that may be adopted to reduce GHG emissions. It is also theoretically possible to reduce a country's GHG emissions by shifting its economic structure from a more– to a less–carbon-intensive one. This has occasionally happened in the past, for example when the 1979 oil price increases raised aluminum production costs so high that producers shut down plants in Japan and Taiwan. However, a country's economic development pattern is generally driven by its human and natural resources, by indigenous and external demand for its products and services, and by its macropolicies. These drivers shift only marginally to accommodate external issues such as oil security or global climate change, and a country's response is typically to pursue policies and technical options that are directed specifically at the externality.

Many cost-effective technical strategies for GHG abatement have been identified for the energy sector of developing nations. These options can be classified into two categories—improving energy efficiency and switching to less–carbon-intensive fuels. Improving energy efficiency reduces the energy used without reducing the level of service. Reduced energy use decreases associated environmental impacts, including emissions of GHGs. Switching to less–carbon-intensive fuels means moving away from fuels that have a higher carbon content per unit of energy to those that have lower carbon content. Among the most commonly used fuels, carbon content decreases from coal to oil to natural gas. Renewable energy sources such as wind, solar energy, and nuclear energy have no direct carbon content. Hydroelectric sources may release CO_2 and methane depending on the type of vegetation and soils beneath their reservoirs (14).

Energy efficiency Opportunities to improve energy efficiency exist on both the supply and the demand side. Supply-side energy efficiency can be increased by improving equipment for power generation and improving transmission and distribution, by reducing the flaring of natural gas, by plugging of pipeline leaks, and by improving coal distribution. Improvements in electricity supply include rehabilitation and efficiency improvements for power plants and rehabilitation and upgrading transmission and distribution systems. Power plants of older vintage typically supply electricity in developing countries because investment capital to build new power plants is scarce. Rehabilitating such power plants and improving their efficiency is thus preferable to acquiring sites and constructing new power plants. Many developing countries have transmission and distribution losses that exceed 20% compared with the approximate 6–8% loss in well-managed systems (15). Reducing transmission losses is cost effective and can lead to significant reductions in fuel use and carbon emissions (16, 17).

Demand-side energy efficiency opportunities include improving the energy performance (*a*) of equipment such as cookstoves, lamps, electric motors, appliances, boilers, buildings, vehicles, etc, and (*b*) of processes, particularly in the energy-intensive industries of aluminum, cement, chemicals, fertilizers, iron and steel, and paper. Cost-effective projects and programs to improve lighting efficiency are being pursued in Mexico and Poland (18, 19). Appliance energy performance is being improved through standards and guidelines in Thailand and South Korea (20), and industrial energy efficiency programs have been successfully pursued in China (17, 21).

Fuel substitution There are opportunities to switch to less–carbon-intensive fuels on both the demand and the supply sides. Demand-side fuel-switching strategies to reduce carbon emissions include the use of compressed natural gas or ethanol in vehicles and the use of renewable biomass sources for cooking. Biomass cookstoves, however, release CO_2 and other GHGs as well, so switching household cooking to biomass fuel may not reduce overall GHG emissions (22, 22a). The use of alternative vehicle fuels has been tried with varying degrees of success in Brazil, Argentina, and India, among other countries (23, 24). Because methane has a GWP 21 times higher than CO_2, small leaks in the natural gas supply network can negate the advantage of switching to this fuel; it is not clear that switching to methane will necessarily lead to reduced CO_2 emissions (25).

Examples of supply-side fuel switching strategies include using combined-cycle, natural-gas–based power plants in place of coal; creating bagasse/biomass cogeneration/bioenergy systems; and using small hydropower, wind, off-grid solar photovoltaics, fuel cells, solar thermal power generation, and other renewable energy sources. Cost-effective opportunities have been demonstrated for wind, small hydro, and sugar cogeneration (26); however, many renewable energy sources may not be cost effective when compared with conventional power plants.

3.1.2 THE BOTTOM-UP APPROACH Although the nature of GHG mitigation assessments varies depending on the GHG-producing activity or sector targeted, the bottom-up approach has a characteristic three-step structure: (*a*) evaluation of GHG reduction and carbon sequestration options, (*b*) development of a baseline scenario, and (*c*) development of GHG reduction, or mitigation, scenarios, including an estimation of scenario costs and GHG mitigation potential.

The first step, evaluation of GHG reduction and carbon sequestration options, involves screening options that are to be evaluated and collecting data on their technical performance, energy use, associated GHG emissions, costs, and other attributes. The second step, developing a baseline scenario, involves estimating GHG emissions or carbon storage in the target sector for a base year and projecting emissions assuming that current development trends continue and no actions are undertaken to explicitly reduce GHG emissions. Development of a baseline scenario requires data on the activities that produce GHG emissions or offer opportunities for carbon storage. Such activity data include industrial production, numbers of urban and rural households, number of vehicles, and demand for forestry products. Projections of future baseline levels of each activity are then based on assumptions about growth in population, gross domestic product, and other macro variables for the country in question (11).

Once a baseline has been constructed, the third step is to assess and rank the GHG mitigation options that are appropriate to the country's energy, economic, and social situation according to their potential impact on GHG emissions. A mitigation scenario may include GHG-reduction or carbon sequestration options that are not included in the baseline scenario and/or that may include a higher penetration of options included in the baseline. Two or more options may be combined to form alternative mitigation scenarios. A mitigation scenario focused on energy efficiency to reduce GHG emissions, for instance, may combine all the efficiency options. The resulting GHG emissions in the mitigation scenario may then be compared with those in the baseline scenario to estimate the emissions reduction achieved through energy efficiency strategies. The efficiency mitigation options may then be ranked in order of their increasing cost per ton of GHG reduced.

The next step is to evaluate the macroeconomic impact of the options in the mitigation scenario; however, few studies have attempted this. Some mitigation assessments have evaluated the investment and trade impacts of options. Mitigation analysis is sector specific, so the final step is to assess and rank options across sectors with respect to the multiple attributes of each option using a multicriteria approach, which is described in Section 3.2.

For the energy sector, types of bottom-up models include the following:

1. Energy accounting models such as LEAP (Long-Range Energy Alternative Planning) and STAIR (Service, Transport, Agriculture, Industry, and Residential) are basically spreadsheet programs in which energy flows are tracked along with related information such as carbon emissions. The models quantify the effects of mitigation policies, which must then be ranked according to the researcher's judgment. STAIR (27), developed at LBNL, has been used in 12 developing countries and modified versions of LEAP (28), developed at the Tellus Institute, Boston, MA, continue to be used in many more countries (29). Although these models cannot easily generate least-cost mitigation solutions, they tend to be simpler to use than optimization models.

2. Engineering optimization models such as EFOM (Energy Flow Optimization Model), ETO (Energy Technology Optimization), and MARKAL (Market Allocation) are linear optimization programs in which the criterion is the total cost of providing economy-wide energy services under different scenarios. The models minimize the cost of providing energy and satisfying end-use demands, ensuring that the amount of energy supplied is at least equal to demand and does not exceed available resource limits. Examples of countries where EFOM has been used in the analysis of carbon emissions costs include Pakistan, Thailand, South Korea, and Vietnam; ETO has been used in Brazil, China, India, and Mexico; and MARKAL has been used in Bangladesh, Nigeria, India, Indonesia, and the Philippines.

3. Iterative equilibrium models, the Energy and Power Evaluation Program (ENPEP), developed at Argonne National Laboratory, Argonne, IL, incorporate the dynamics of market processes related to energy via an explicit representation of the balancing of energy supply and demand (30). ENPEP has been used in Venezuela, Peru, and Argentina, and in several East European countries.

3.1.3 CARBON EMISSIONS SCENARIOS

Each bottom-up mitigation study has prepared a baseline or reference scenario and one or more abatement or mitigation scenarios of CO_2 emissions. We analyze these scenarios by evaluating the factors contributing to CO_2 emissions, which can be expressed in terms of primary energy use, population, and a nation's GDP, using the following identity (31):

$$\begin{aligned} CO_2 \text{ emissions} = {} & \text{population} \times \text{GDP/population} \times \text{energy/GDP} \\ & \times CO_2\text{/energy.} \end{aligned}$$

Bottom-up approaches assume GDP and population growth rates as basic drivers for energy and CO_2 emissions growth. The energy/GDP ratio provides an indication of a nation's aggregate energy intensity or the energy needed to support a unit of economic activity; the CO_2/energy component provides information on the carbon intensity of the mix of fuels that supply primary energy. Changes in energy/GDP ratio may be caused either by structural change in the composition of GDP or by technical energy efficiency improvements. The latter is influenced by the types of energy efficiency mitigation options considered. Changes in the CO_2/energy component may be brought about by a change in the mix of fuels from coal to natural gas or other mitigation options (described in Section 3.1.1).

Table 2 shows the population and GDP growth rates assumed in various country studies conducted since 1991. It also shows the resulting primary energy and CO_2 emissions growth rates that were projected by each study for the baseline and mitigation scenarios. The base year for the studies ranges from 1985 to 1995, and the target year for the projection ranges from 2020 to 2030. The studies used different methods to create their scenarios; these are noted in the second-to-last column of the table. Table 3 shows the elements of the identity noted above for the same country studies.

The population growth rates in all studies are derived from national statistics. These growth rates vary from a low of 0.5% for South Korea to about 3% for some African countries. Population growth rates are declining in most developing countries, except in some countries in Africa and the Middle East where they are projected to increase in the near future (32). These overall population growth rates mask much higher urban growth rates, which exceed 8% in African countries. Urban growth rates are important because much of the modern fuel use and its consequent CO_2 emissions occur in cities. The more recent China and India ALGAS studies (Table 2) show higher population growth rates than earlier ones, indicating pessimism about the success of family planning programs in those countries.

The GDP growth rates shown in Table 2 for the 1991 LBNL studies (29) were set by individual researchers after examining historical growth rates and income distribution, and for the UNEP studies using national macroeconomic plans or targets. The LBNL studies asked researchers to imagine what GDP level their

Table 2 Growth rates of population, gross domestic product (GDP), primary energy consumption, and CO_2 emissions

Country[a]	Population	GDP	Primary energy Baseline	Primary energy Mitigation	CO_2 emissions Baseline	CO_2 emissions Mitigation	Reduction in target year (%)	Type of model	Sources
Africa									
Ghana (1987–2025)	2.90%	4.00%	3.6%	3.00%	5.4%	5.00%	14%	Accounting	5
Senegal (1990–2020)	3.00%	3.20%	3.2%	2.4%	3.5%	2.60%	24%	Accounting	6
Sierra Leone (1987–2025)	2.30%	3.00%	2.2%	1.70%	3.5%	3.00%	17%	Accounting	5
Nigeria (1990–2030)-I	2.80%	2.00%	1.80%	1.4%	2.00%	1.4%	20%	Optimization	40
Nigeria (1990–2030)-II	2.40%	3.00%	2.00%	1.6%	2.60%	2.0%	20%	Optimization	40
Nigeria (1990–2030)-III	2.00%	5.00%	2.60%	2.1%	3.20%	2.7%	19%	Optimization	40
Latin America									
Argentina (1990–2025)	1.10%	2.00%	1.80%	1.1%	1.80%	1.1%	22%	Accounting	5
Brazil (1985–2025)	1.20%	3.20%	2.50%	1.0%	2.80%	0.8%	55%	Accounting	5
Brazil (1990–2025)	1.40%	4.70%	3.50%	3.7%	5.30%	3.2%	52%	Optimization	6
Brazil (1985–2025)	1.35%	4.30%	3.60%	3.70%	4.30%	2.50%	51%	Optimization	39
Mexico (1987–2025)	1.70%	4.40%	2.7%	2.0%	2.9%	2.0%	30%	Accounting	5
Venezuela (1984–2025)	1.70%	4.00%	3.40%	3.2%	2.50%	1.9%	22%	Accounting	5
Venezuela (1990–2025)	2.10%	3.80%	2.50%	1.9%	3.10%	2.1%	30%	Accounting	6
Venezuela (1990–2025)	2.25%	4.00%	3.2%		2.3%			Iterative	34
Asia									
China (1990–2020)	0.70%	4.90%	3.30%	2.90%	3.10%	2.20%	24%	Optimization	39
China (1990–2020)-I	0.9%	7.2%	3.6%	3.2%	3.7%	2.7%	26%	Optimization	42
China (1990–2020)-II	0.9%	7.2%	3.6%	3.0%	3.7%	2.1%	38%	Optimization	42
China (1990–2030)	0.8%	7.2%	3.2%		2.9%			Optimization	94
India (1985–2025)-I	1.25%	4.90%	5.40%	4.70%	5.30%	4.30%	33%	Optimization	39
India (1990–2020)	1.5%	5.7%	4.9%		4.9%			Optimization	42
Indonesia (1990–2020)		7.00%	5.7%	5.5%	7.1%	6.3%	20%	Optimization	41
Nepal (1990–2030)	1.60%	4.50%	1.3%		5.7%			Optimization	35
South Korea (1995–2020)-I	0.5%	3.8%	2.7%	2.3%	3.6%	3.1%	12%	Optimization	42
South Korea (1995–2020)-II	0.5%	3.8%	2.7%	2.1%	3.6%	2.9%	17%	Optimization	42

[a]Numbers in parentheses indicate the scenario time period.

Table 3 Key elasticities in baseline and mitigation scenarios[a]

	Baseline			Mitigation			
Country[b]	E/GDP	CO_2/E	CO_2/GDP	E/GDP	CO_2/E	CO_2/GDP	Sources
Africa							
Ghana (1987–2025)	0.90	1.50	1.35	0.75	1.67	1.25	5
Senegal (1990–2020)	1.00	1.09	1.09	0.75	1.08	0.81	6
Sierra Leone (1987–2025)	0.73	1.59	1.17	0.57	1.76	1.00	5
Nigeria (1990–2030)-I	0.90	1.11	1.00	0.70	1.02	0.71	40
Nigeria (1990–2030)-II	0.67	1.30	0.87	0.52	1.31	0.68	40
Nigeria (1990–2030)-III	0.52	1.23	0.64	0.43	1.25	0.53	40
Latin America							
Argentina (1990–2025)	0.90	1.00	0.90	0.55	1.00	0.55	5
Brazil (1985–2025)	0.78	1.12	0.88	0.31	0.80	0.25	5
Brazil (1990–2025)	0.74	1.51	1.13	0.79	0.86	0.68	6
Brazil (1985–2025)	0.84	1.19	1.00	0.86	0.68	0.58	39
Mexico (1987–2025)	0.61	1.07	0.66	0.46	0.96	0.45	5
Venezuela (1984–2025)	0.85	0.74	0.63	0.80	0.59	0.48	5
Venezuela (1990–2025)	0.66	1.24	0.82	0.50	1.11	0.55	6
Venezuela (1990–2025)	0.81	0.71	0.57				34
Asia							
China (1990–2020)	0.67	0.94	0.63	0.59	0.76	0.45	39
China (1990–2020)-I	0.50	1.01	0.51	0.45	0.83	0.37	42
China (1990–2020)-II	0.50	1.01	0.51	0.42	0.69	0.29	42
China (1990–2030)	0.44	0.89	0.40				94
India (1985–2025)	1.10	0.98	1.08	0.96	0.91	0.88	39
India (1990–2020)	0.87	1.00	0.86				42
Indonesia (1990–2020)	0.81	1.25	1.01	0.79	1.15	0.91	41
Nepal (1990–2030)	0.29	4.40	1.27			0.00	35
S. Korea (1995–2020)-I	0.70	1.36	0.96	0.60	1.36	0.82	42
S. Korea (1995–2020)-II	0.70	1.36	0.96	0.56	1.38	0.77	42

[a]E, Energy; GDP, gross domestic product; CO_2, carbon dioxide emissions.
[b]Numbers in parentheses indicate scenario time period.

country might reach by the target year and which country today was close to that future level. So a future Brazil might be patterned after contemporary Spain or Japan, depending on the assumed growth rates and income distribution. The GDP growth rates vary across countries and within a country during different time periods. The earlier 1991 study shown in Table 2 for Brazil assumed a lower growth rate of 3.2% because the economy was in recession in the late 1980s. The economic situation at the time a study is done affects long-term projected growth rates, which are, for example, high for Indonesia in Table 2, a country that appears to be facing economic ruin today. The assumed GDP growth rates for the more recent India and China ALGAS studies shown in

Table 2 are higher than the earlier ones, reflecting 1990s optimism about their prospects for future economic growth.

Table 2 also shows the emissions reduction achieved in the mitigation scenario relative to the baseline one in the last or target year of each study. The emissions reduction varies from about 12% for one of the South Korea scenarios to over 50% for Brazil. The extent of emissions reduction in each scenario depends on which mitigation options are already captured in the baseline scenario. If a substantial portion of the mitigation options are already included in the baseline scenario, because they are assumed to have been implemented for other good reasons, then the extent of reduction in the mitigation scenario will be lower and vice versa. Second, in order to determine the extent of emissions reduction in the mitigation scenario modelers chose an emissions-reduction target or they ran the model until demand or resource constraints dictated that no further reductions could be achieved. In the case of Senegal and Nigeria, a 25% and 20% target reduction was chosen by the modelers; for the Brazil and Venezuela UNEP studies a 50% and 25% target was selected; and for the Indonesia study a 20% target was aimed at. For the China, Brazil, and India studies reported in AMBIO (39), the model was run until it ran into constraints on capital and foreign exchange. For the 1991 LBNL studies, the modelers used their best judgement on the extent to which technological change could occur by the 2025 target year. Each approach is eventually constrained by the types and numbers of mitigation technologies that are included in the analysis.

In virtually all studies, energy intensity (energy/GDP) declines in the future as less energy is used per unit of economic growth. The decline results from both structural changes as economies shift from energy-intensive and other manufacturing to service sectors, and from technical improvements in energy efficiency. For instance, China's energy/GDP elasticity has hovered around 0.5 since 1980; a recent study shows that almost two thirds of China's decline in energy intensity during this period was because of structural change (21, 21a). This trend is assumed to continue in the future in the China studies cited in Table 3; recent Chinese studies report a low energy/GDP ratio of 0.44–0.46. The energy/GDP ratio for India was higher than 1 until 1992 but has declined since then at an elasticity of 0.92 (33). In an earlier India study that used pre-1992 data, the energy/GDP elasticity was 1.1; this figure declined to 0.87 in the recent India ALGAS study (shown in Table 3).

In the mitigation case, the GDP growth rate and structure are assumed to be the same as in the baseline scenario for all studies reported in Table 2. The lower energy/GDP elasticity in the mitigation case is therefore the result of more efficient technical use of energy compared with the baseline. Brazil is an exception because increased amounts of ethanol substitute for vehicle gasoline in the mitigation scenario, which increases the energy intensity from 0.74 and 0.84 in the baseline to 0.79 and 0.86 in the mitigation scenarios (Table 3).

The carbon intensity of primary energy (CO_2/energy) is generally projected to increase in the baseline scenario, as evidenced by an elasticity value higher than 1 for almost all countries except Venezuela, where the share of natural gas is projected to increase (Table 2). This increase in carbon intensity occurs, in part, because the studies show countries moving toward using increased amounts of coal for power generation (33a). An earlier study showed that many large developing countries planned to use coal for a larger share of their electricity generation rather than hydroelectricity (15). Increased use of natural gas could offset this trend, however. With privatization in vogue in cash-strapped developing countries, natural gas, where available, is the fuel of choice for private producers because it requires less investment per kilowatt of unit capacity than do coal power plants. Greater natural gas use could hold projected higher carbon intensities in check. In Venezuela, for example, where the proportion of natural gas use is expected to increase in all sectors, the elasticity value is less than 1 for the baseline scenario (34). The Venezuelan mitigation scenario assumes that natural gas use increases beyond what is projected in the baseline scenario and also that penetration of renewable energy technologies increases modestly (Table 3).

The abundance of domestic hydro resources in a country can greatly reduce the CO_2/energy elasticity. In Brazil, the UNEP and AMBIO studies (see Table 3) show a sharp drop in the CO_2/energy elasticity between the baseline and mitigation scenarios because of increased use of hydro in place of future thermal power generation. The China ALGAS study's second scenario reports a similar sharp drop brought about by increased use of hydro, nuclear, and other forms of renewable energy. Where domestic renewable energy resources are scarce (India and South Korea), the CO_2/energy elasticity does not decline as much between the two scenarios. Much of the energy demand in Indonesia is on Java, an island with limited renewable energy sources, which limits the potential for reducing the CO_2/energy elasticity in Indonesia.

A second reason for the high CO_2/energy elasticity shown in Table 3 for Asian and African countries, particularly Nepal and the smaller countries in Africa, is an anticipated shift away from biomass to kerosene and liquified petroleum gas (LPG) for cooking and water heating. For example, in Nepal, the share of biomass, which is assumed to be entirely renewable annually and thus to emit no net CO_2, declines from 95% in 1990 to 70% by 2030 (35). This decline causes Nepal's CO_2/energy elasticity to reach 4.4.

Table 3 also shows the CO_2/GDP elasticity, which is a product of the other two elasticities. The low energy/GDP elasticity is offset by the higher carbon/energy elasticity, which means that the carbon emissions per unit of GDP do not decline as much as future energy intensity.

3.1.4 COST OF MITIGATION OPTIONS Each study country has identified many mitigation options that could be pursued to reduce GHG emissions relative to the baseline scenario. The options are ranked in order of increasing cost so as to provide guidance to policy makers regarding priorities for implementation. As we discuss in Section 3.2, priorities may shift as attributes other than cost are considered.

Most mitigation analyses define costs so as to include equipment, labor, materials, and fuels. Transaction and administrative costs of actually implementing an option are often not included in these analyses. The life-cycle cost of a mitigation option may be higher or lower in comparison with its alternative in the baseline scenario. For many reasons, which have been collectively called "market barriers," a mitigation option with lower life-cycle cost, i.e. that is cost effective, may not show up in the baseline scenario. Such options are known as "no-regret" options because their inclusion in a mitigation scenario will lower the cost of providing energy service, so the mitigation scenario will exhibit "negative" cost relative to the baseline scenario. If the monetary and other costs of overcoming market barriers are not prohibitive, it is clearly worth pursuing a negative cost option before pursuing options with positive costs.

Cost analysis using accounting models Accounting models provide the costs of individual mitigation options, so options can be ranked by cost with respect to their carbon savings.

A summary of abatement measures and costs from the UNEP studies is given in Table 4. Costs are reported only for a few high-potential measures and are incremental abatement costs for each option, i.e. the cost of each option relative to the cost of the alternative option in the baseline scenario. Table 4 shows that abatement costs vary considerably for different measures and across countries. The variation can be attributed to differences in economic structure and energy supply and demand patterns in the study countries as well as to differences in study methodology. Studies that emphasized energy conservation show numerous negative cost options in demand-side efficiency improvement. Supply-side fuel-substitution options turn out to be expensive, and renewable energy options are even more costly. Infrastructure options, such as changes in transportation modes, are the most expensive. The Venezuela study found that energy conservation options have positive incremental abatement costs; in contrast, reported costs for similar energy conservation options in Egypt and Thailand were negative. A later study of mitigation options for Venezuela found that costs for several promising mitigation options were negative (34). These options include improving the fuel efficiency of industrial boilers and furnaces, reducing bus size to increase their passenger load factors, switching to natural gas, and developing hydro reservoirs. Such improvements could reduce

Table 4 Main categories of CO_2 reduction options and related marginal abatement cost (MAC) in the participating developing countries for the long-term target[a]

Country	CO_2 reduction option	Reduction (%)	MAC (US$)
Brazil	Electricity savings (industry, services and residential)	7	−66
	Solar uses in agriculture	1	22
	Fuelwood and charcoal for afforestation programmes	21	24
	Ethanol, bagasse and electricity generation from bagasse	19	29
	Total CO_2 reductions	48	
Egypt	Fuel switching in households	6	−21
	Efficient industrial equipment and maintenance	10	−12
	Transportation	2	−12
	Heat recovery and new industrial processes	9	−8
	New raw materials	5	−3
	Efficient household appliances	5	−3
	Electricity generation	8	−1
	Efficient stoves	7	2
	Total CO_2 reductions	52	
Senegal	Early hydropower implementation	0.1	−210
	Agriculture intensification	5	−28
	Energy conservation in industry	0.4	−4
	Dissemination of improved stoves	11	0
	Improve carbonisation efficiency	13	1
	LPG-charcoal substitution	15	2
	Biomass from afforestation	6	3
	Total CO_2 reductions	50	
Thailand	Efficient air conditioners	2	−36
	Electronic ballast	1	−27
	Compact fluorescent lamps (service sector)	6	−14
	Compact fluorescent lamps (residential sector)	2	−9
	Nuclear electricity	18	20
	Highly efficient gasoline cars	1	92
	Total CO_2 reductions	30	
Venezuela	Reduced flaring and leakage of methane	7	3
	Efficient boilers and kilns	10	10
	Freight transport	1	13
	Efficient electric motors in the industrial sector	2	17
	Passenger transport	4	21
	Electric sector	0.6	35
	Other energy savings in the industrial sector	2	39
	Efficient electrical appliances	0.4	52
	Total CO_2 reductions	27	
Zimbabwe	Efficient boilers	23	−9
	Energy savings in the industrial sector	4	−2
	Efficient motors and power factor correction	2	−2
	Increased hydropower	5	5
	Efficient furnaces	2	66
	Central photovoltaic power	1	153
	Coal for ammonia	1	289
	Total CO_2 reductions	38	

[a]From Reference 6.

Venezuela's cumulative carbon emissions from 1990 to 2025 by 85 MtC or 8.3% of the projected baseline emissions at a negative average cost per tonne of carbon (34).

Cost analysis using optimization models Optimization models are used to develop scenarios or combinations of mitigation options that minimize the cost of providing energy services for a country's economy. Results from these models are often presented in terms of the costs of a scenario rather than costs of individual options. Key results from GHG mitigation studies for India (36), China (37), and Brazil (38) are analyzed by Sathaye et al (39). The three studies all used variants of the ETO engineering optimization model.

For each of the three countries, two scenarios were analyzed for the period from 1985/1990 to 2020/2025. The first is a current trends or baseline scenario and the second is a low carbon or mitigation scenario. Values of factors such as population growth, economic activity (Table 2), sector structure, and technical progress are assumed as exogenous inputs into the analysis of each country. Results from the studies are summarized in Table 5.

For India, the low-carbon case reduces the cost of providing energy services by 13% in the year 2025 while reducing carbon emissions by 32%. The cost of conserved carbon (CCC) is thus negative at −58 US$/tC. The negative cost options include opportunities to improve energy efficiency as well as switching to natural gas. Mongia et al (36) show that efficiency improvements and improved fuel allocation independently yield negative CCCs, implying that the government needs to focus on improving energy efficiency as well as changing economic signals regarding fuel choice. In contrast, the reduction of carbon emissions in the low-carbon scenario in China has a positive cost of 117 US$/tC because energy efficiency improvements are already included in an aggressive baseline scenario with an energy/GDP elasticity of 0.67 (Table 3). In Brazil, the cost of providing energy services is almost the same for both the current trends and the low-carbon scenarios. Because carbon emissions in the low-carbon scenario are about half those in the current trends scenario, the CCC is negative.

Another optimization-type study for India was conducted using the MARKAL model (33). The technology representation in this study is quite detailed; 600 present and future technologies are included. The study analyzed five carbon-tax scenarios, ranging from a no-tax scenario to a stabilization-tax scenario in which the tax is the amount estimated to be necessary to stabilize India's GHG emissions over the long term (the tax grows from \$12/tC in 1995 to \$162/tC in 2035). Carbon emissions under the stabilization tax are 25% lower in 2035 compared with the no-tax scenario. Successively higher tax levels lead to lower emissions, but marginal mitigation gains are low at higher tax levels.

Table 5 Carbon emissions, energy use, and cost of conserved carbon[a]

China	1990	2020	Annual growth (%)	Percent change
Carbon emissions (Tg)—CT	657	1671	3.1	
Carbon emissions (Tg)—LC	657	1262	2.2	25
Primary energy—CT (Mtoe)	694	1875	3.3	
Primary energy—LC (Mtoe)	694	1666	2.9	11
CCC ($/MgC)		117		
India	**1985**	**2025**	**Annual growth (%)**	**Percent change**
Carbon emissions (Tg)—CT	115	960	5.3	
Carbon emissions (Tg)—LC	115	652	4.3	32
Primary energy—CT (Mtoe)	135	1173	5.4	
Primary energy—LC (Mtoe)	135	891	4.7	24
CCC ($/MgC)		−58		
Brazil	**1985**	**2025**	**Annual growth (%)**	**Percent change**
Carbon emissions (Tg)—CT	72	394	4.3	
Carbon emissions (Tg)—LC	72	197	2.5	50
Primary energy—CT (Mtoe)	171	710	3.6	
Primary energy—LC (Mtoe)	171	735	3.7	4
CCC ($/MgC)		−25		

[a]CCC, Cost of conserved carbon; Tg, teragrams; CT, current trends; LC, low carbon; Mtoe, million tons of oil equivalent; $/MgC, dollars per million grams of carbon.

Implementation of a carbon tax reduces emissions by promoting a change in fuel mix—replacing coal with gas and, to a lesser extent, with hydro and renewable energy. Coal demand declines drastically in response to higher carbon taxes. The penetration of renewable technologies and use of wind power and small hydropower plants could increase significantly in India if a carbon tax were implemented.

Nigeria A MARKAL optimization study of GHG mitigation options for Nigeria defined low-, medium-, and high-growth scenarios for the country's economy (Tables 2 and 3) and extrapolated baselines according to current trends and projected industrial and other developments (40). Four sets of GHG emissions abatement options were considered: demand-side mitigation in the residential, industrial, and transportation sectors; supply-side mitigation for electricity generation and oil refineries; fuel switching to increased natural gas use in industry; and increased use of renewable energy. Two mitigation goals were set: 20% and 35% reductions from the projected baseline by the year 2030. Reduction of gas flaring in the Nigerian oil industry was identified as a key component in achieving these percentage reductions in future GHG emissions. The most promising mitigation options in the residential sector were introduction of efficient lighting and improved kerosene stoves. Efficient motors and substitution of natural gas for oil for process heat were identified as the most promising options in the industrial sector. Incremental costs for mitigation strategies were calculated as the difference between the discounted total energy system cost of an emissions reduction scenario and the corresponding discounted energy cost of the baseline scenario. In low-, medium-, and high-growth scenarios, the marginal and average cost of a cumulative 20% reduction of CO_2 in the energy sector is less than US $30 and $5, respectively, per ton of CO_2.

Indonesia A recent MARKAL analysis of GHG mitigation options for Indonesia used current energy use trends to establish a baseline scenario, with energy use projected to grow at a rate of 6.6% annually (Tables 2 and 3) (41). The baseline and mitigation scenarios extend to the year 2020. Mitigation options for the residential sector include installation of energy-efficient lighting, substitution of solar home systems for kerosene lamps, improvement in refrigerator and air conditioning efficiency, and substitution of LPG for kerosene stoves. For the industrial sector, mitigation strategies include introduction of variable-speed motors and cogeneration of heat and power. In the commercial sector, mitigation options include improvements in lighting and air-conditioning efficiency and use of solar collectors for hot-water heating. Advanced power plant technologies, such as integrated coal gasification and combined cycle generation, were also included in the model. The mitigation scenario aimed to reduce CO_2 emissions by 10% from the baseline in the year 2010 and 20% in 2020. The total annual investment for the energy system (including public and private expenditures) in 2020 were estimated to be US $47 billion (in 1989 dollars) for the baseline scenario and $50 billion for the mitigation scenario.

3.1.5 FOREIGN EXCHANGE AND INVESTMENT REQUIREMENTS Decisions regarding fuel and technology options in developing countries are often based on the investment and foreign currency implications of the options rather than annualized costs. Investment and foreign currency consequences of pursuing mitigation options were studied for Brazil, China, and India (Table 6) (39). For India, the combined investment and foreign exchange required for the energy sector as a share of GDP is 10.1% in the year 2025 in the current trends scenario and 9.6% in the low-carbon scenario. In the latter, natural gas imports reduce the capital cost of electricity generation but add to foreign exchange requirements.

In China, energy system investment as a percentage of GDP in 2020 is less in the low-carbon scenario, but the foreign exchange requirement is much higher

Table 6 Investment and foreign exchange as percent of gross domestic product

China	1990	Current trends (2020)	Low carbon (2020)
Investment (%)	4.6	2.8	2.3
Foreign exchange (%)	−1.2	−0.1	5.1

India	1985	Current trends (2025)	Low carbon (2025)
Investment (%)	4.1	4.8	3.4
Foreign exchange (%)	1.9	5.3	6.2

Brazil	1985	Current trends (2025)	Low carbon (2025)
Investment (%)	3.0	8.0	9.0
Foreign exchange (%)	1.0	3.0	1.0

(5.1% of GDP versus −0.1% in current trends). Holding the foreign exchange outflow to 5% of GDP limits the extent to which emissions can be lowered through import of natural gas. A more recent Chinese study (42) corroborates these findings and shows that 25% emissions reductions are possible compared with the baseline in 2020, with only a modest share, about 6%, of the GDP going for investment and fuel imports compared with 5% in the baseline scenario. The share actually declines from 1990 as energy efficiency improvements lead to a sharp decrease in the energy/GDP elasticity, to 0.42, down from 0.5 in the baseline scenario.

For Brazil, investment and foreign exchange increase to 10–11% of GDP in 2025 for both scenarios. Investment requirements rise slightly in the low-carbon scenario because of increased use of hydropower. In Brazil, however, the reduction in carbon emissions is partly achieved through increased use of indigenous biomass-derived fuels, which reduces the foreign exchange share of GDP to only one third the share in the current trends scenario.

3.1.6 IMPACT OF MITIGATION ON WORLD OIL AND NATURAL GAS MARKET Results from the country studies reported above show that the increased use of natural gas, and in some countries oil, can have significant implications for the world oil and gas market. In 1990, the combined oil use in three of the larger countries discussed above—Brazil, China, and India—was 4.5 million barrels per day (mbpd). It reaches 15.2 mbpd by 2020/2025 in the baseline (current trends) scenario (39), which is a more than a threefold increase. About half of this oil is assumed to be imported. Reducing future carbon emissions increases oil use in China but reduces it in India and Brazil, for a net oil use reduction of 5% compared with the baseline scenario.

The larger impact, however, is on the use and imports of natural gas. Total natural gas use in the three countries increases from less than 1 mbpd in 1990 to a 10.7-mbpd equivalent in the target years in the baseline (current trends) scenario, assuming that the price of imported natural gas is tied to that of world oil imports. In the mitigation (low carbon) scenario, natural gas use expands almost fourfold in China and increases by 20% in India. In contrast, Brazilian gas use declines as use of renewable energy sources increases. For the three countries, total gas use increases 50%, to 15.9 mbpd. This level of natural gas use may be compared with the quantity of natural gas traded globally, which amounted to 4.5-mbpd equivalent in 1993 (43). The world market for natural gas may become tight if other countries also choose to use natural gas to reduce their GHG emissions.

3.2 *Results from GHG Mitigation Studies: Multicriteria Approach*

The studies reported above provide carbon mitigation scenarios based on the economic potential of each mitigation option,[2] which ignores the many market barriers to their penetration. Barriers to improvements in energy efficiency or fuel switching may arise for or from any of the participants in energy transactions. These include energy consumers, end-use equipment manufacturers and providers, producers and distributors of energy, actual and potential cogenerators, local/national financial institutions, governments, and funding agencies (44). Policies and measures may be necessary to overcome these barriers. Cost analysis by itself is usually not sufficient to capture all the costs that these barriers represent. Multicriteria analysis has been used in some developing country mitigation studies to explicitly include these barriers in ranking mitigation options (45).

Multicriteria approaches permit the evaluation of mitigation options with respect to both quantifiable and nonquantifiable attributes. These approaches allow an explicit consideration of criteria, such as institutional capacity for implementation, that are difficult to quantify in terms of cost. The Analytical Hierarchy Process (AHP) is a multicriteria model that has been used for mitigation analysis by many countries (46). It works on the basis of a pairwise

[2]Economic potential is the portion of the technical potential for GHG emissions reductions or energy efficiency improvements that could be achieved cost effectively in the absence of market barriers (IPCC, 1997) (43a). Technical potential is defined as the amount by which it is possible to reduce GHG emissions or improve energy efficiency by using a technology or practice in all applications for which it could technically be adopted, without consideration of its costs or practical feasibility.

comparison of mitigation options with respect to each criterion. The decision maker is then asked to weigh each criterion also using a pairwise comparison. The AHP model then ranks the options using all the criteria and provides information on the contribution of each criterion to the ranking of options. Examples of countries where HIPRE+3/AHP have been used for mitigation analysis include Pakistan, India, China, and Tanzania.

A recent country study of Pakistan illustrates the use of multicriteria analysis to evaluate 22 mitigation options that had been ranked using the LEAP model. The least-cost option in this set is cogeneration followed by efficient lighting, fans, groundwater pumping, transmission and distribution (T&D) loss reduction, and, finally, photovoltaic units. The HIPRE+3 multicriteria model was used to evaluate the mitigation options. The quantitative criteria used were the financial rate of return, emissions reduction potential, and net present value of benefits; qualitative criteria were local environmental impact, social acceptability, and market barriers. This multicriteria analysis changes the purely cost-based ranking of options that was generated using the LEAP model. For instance, the ranking of energy-efficient fans dropped from second place to sixth once the inability of small local manufacturers to make these high-efficiency products was factored in, and that of T&D loss reduction moved up from fifth to second once the government's initiatives and promotion to achieve this prior to an overall restructuring of the power sector were factored in.

3.3 *Results from GHG Mitigation Studies: Top-Down Approach*

The top-down approach is used to analyze the impact of changes in economic instruments, such as taxes and subsidies, on aggregate economic behavior, which is usually measured by a nation's GDP. The approach explicitly includes feedback between the energy system and the other economic sectors as well as with the macroeconomic performance of the economy.

Most bottom-up and top-down approaches simulate a country's energy economy using assumptions that ignore the complex institutional structures that make an energy economy function. The bottom-up approach tends to be optimistic about future GHG abatement opportunities and identifies numerous "no regret" and low-cost energy efficiency options. The optimism reflects the perspective that the present technology mix does not minimize the cost of providing energy services, which it identifies as many no regret energy efficiency and fuel-switching options. The abatement costs derived from bottom-up studies often ignore implementation costs, including the costs of overcoming the barriers to achieving energy efficiency.

The pessimism of the top-down approach originates from the assumption that the present technology mix results from efficient behavior by consumers and firms under prevailing economic conditions. The application of the top-down approach to developing countries suffers from unrealistic assumptions about the existence of free markets. Recent approaches, one for Venezuela (47) and another for Nigeria (40), have tried to break this mold (see Section 3.3.1).

3.3.1 TOP-DOWN MODELS Several top-down models have been used to analyze the GDP impacts of tax policies to reduce carbon emissions (48, 49). We report on four of these models, which have been used to analyze GDP impacts of mitigation policies in developing countries.

A model similar to the OECD general equilibrium environmental (GREEN) model has been developed in China by Zhang (51). The computable general equilibrium (CGE)-China model is a time-recursive dynamic model. Energy use is disaggregated into four categories: coal, oil, natural gas, and electricity. The model has been calibrated to a 10-sector social accounting matrix (SAM) version from 1987.

One drawback of the model is that it is not able to represent specific technologies. The production relationships used in the model are averages for the whole energy sector, for example, and tend to obscure diverse underlying processes and behavior. The second generation model (SGM) addresses this limitation by utilizing technologies rather than sectors as its fundamental unit of disaggregation among production activities within an otherwise conventional CGE structure. The SGM model has 20 sectors, with the energy sector divided by electricity generation and fuel supply technologies. Capital stock, however, is not malleable and cannot be shifted from one economic sector to another. The model can represent individual country data. (We report on its application to India below.) The SGM model, however, lacks a detailed representation of energy-consuming sectors; in addition, technological change, a key parameter in determining the extent to which energy efficiency may improve, has to be input exogenously.

The LBL-CGE model is a static multisector model designed for analyzing macroeconomic effects of investments in the energy sector and on the effects of energy price increases on sectoral energy consumption. These are contrasted with the effects of investments to improve energy efficiency. A unique feature of the LBL-CGE model is that it is a structuralist CGE-type model as opposed to a neo-classical construct like that used in the SGM or GREEN models, which emphasize macro-behavioral functions. Structuralist models can reflect factors such as control of the means of production by distinct types of actors (private sector, state, or transnational capital), the functioning of financial intermediaries, the degree of concentration of markets, etc. How prices and production equilibrate is determined primarily by a model's causal structure and secondarily by substitution response.

The MIMEC model has been used to study development, energy, and environmental policy in Egypt and India (50). A distinctive feature of this model is its use of a process analysis form of input-output analysis to summarize an economy's production possibilities. It can link in-depth analysis of selected industries to overall economic activity by addressing specific information on costs and energy savings according to technology type. The time horizon of the model is formally fixed to 100 years, which allows for fundamental changes in the economy and energy system. The time horizon also justifies the assumption of flexible prices. The model consists of six nonenergy and four energy sectors.

3.3.2 RESULTS The baseline scenario extends to the year 2010. The aggregated results show relatively small decreases in growth and consumption, especially for the 20% emissions reduction objective. The results of the CGE-China model are fairly close to the results of the OECD global model GREEN (52). The main reason for this is probably the assumption of operational markets for factors of production, products, and foreign exchange. It is questionable whether this assumption holds over a time horizon of only 20 years in China. An interesting result of the different scenarios is that transportation is hardly affected by a 20% reduction in emissions, but a 30% reduction entails a transportation decrease of 14%. This indicates that all "cheap" energy options are utilized to achieve the 20% reduction and that any reduction targets beyond 20% will result in considerable macroeconomic losses.

India A top-down model originally designed for industrialized countries, the SGM (53), was applied to India (33). Carbon emissions in the SGM reference scenario are three times higher in the year 2030 than in 1990. A "1X" mitigation scenario assumes the application of a carbon tax to stabilize future carbon emissions at the 1990 level. A "2X" scenario assumes that carbon emissions stabilize at twice the 1990 level. The SGM computes the optimal carbon-tax trajectory for achieving each mitigation scenario.

The carbon tax that is necessary to achieve the 1X scenario is extremely high. Meeting this emission target requires adjustments in the economy, including totally phasing out coal-based electric power by the year 2010, as well as large investments in nuclear and renewable energy and energy-efficient technologies. The tax level required for achieving the 2X scenario rises from approximately \$25/tC in 2015 to approximately \$150/tC in 2030. The GNP loss in the 2X scenario in 2030 is 3%.

Venezuela and Nigeria Two separate structuralist CGE models that share the same core structure were developed to simulate macroeconomic effects of different policies in relation to CO_2 reduction for Venezuela (47) and Nigeria (40).

To correctly simulate the energy/economy interaction in these and other developing countries, the models allow prices of selected fuels to be fixed by the government. Both Venezuela and Nigeria are large oil producers and members of the Organization of Petroleum Exporting Countries (OPEC), and both economies rely heavily on oil revenue.

The Venezuela model was designed to evaluate the impact on GDP of two types of policies: higher taxes on petroleum products, which would induce lower fuel demand and CO_2 emissions; and an increase in capital investment for improving energy efficiency, thus lowering emissions. The latter simulates the type of activity that might occur under a joint implementation[3] project. The model shows that higher investment leads to positive GDP and other impacts and can be used to moderate the negative GDP impact of higher prices, which might reduce emissions.

The Nigeria model (40) includes 13 sectors. The main policies and options simulated include taxation, price reform, and efficiency improvements, which reduce emissions, but differ in their impacts on the economy. Taxation and price reform achieve GHG reduction with a negative impact on the economy (GDP, output, and employment), and efficiency improvement leads to increased economic growth. It was also found that the negative impacts of the taxation and price reform simulations were minimized when these options were combined with efficiency improvements.

Egypt A study of the impact on GDP of CO_2 emissions reduction for Egypt (54) used a CGE model, including intertemporal optimizing.

CO_2 emission reductions targets of 20% to 50% result in considerable drops in annual GDP growth rate in the years in which they are introduced. The initial drop in GDP is large, especially for the 40% reduction. For the 20% reduction the economy shows the ability to recover within approximately 25 years. Sectors with high energy intensity show the largest drop in growth rates compared with the baseline scenario.

The Egypt study includes scenarios where backstop technologies are introduced. The backstop technologies are all known options, though they are not utilized currently in Egypt. Introduction of backstop technology reduces the GDP loss. With a 20% reduction and backstop technologies, the GDP loss is turned to a gain after approximately 10 to 15 years. A scenario including renewable electricity technologies is also simulated. The consequence of using renewable energy as a backstop technology is larger fluctuations in the change in GDP, i.e. larger initial GDP loss followed by a smaller loss later.

[3]Joint implementation refers to projects for which investment is provided by an entity from another country, in return for which the investor country may receive carbon credits arising from the project (see Section 5 for more on joint implementation).

3.4 *Summary of Key Findings from the Energy Sector Mitigation Studies*

Developing-country carbon emissions from fossil-fuel combustion and natural gas flaring have increased at a rate of 4.4% compared with the world average of less than 1% between 1990 and 1996 (Table 1). China and India, which have two of the largest developing country populations, and South Korea accounted for over half of the 2260 MtC emissions in 1996 from developing countries. At current growth rates (see Table 1) these emissions from developing countries will pass or match those from the industrialized countries in 7 years.

Is it possible to slow the growth of emissions from developing countries? Many of the studies reviewed in Table 3 suggest that future energy/GDP growth rates may be lower than historical ones. This decline would result from an anticipated change in economic structure as service industries begin to dominate and also as rapid stock turnover and energy efficiency programs and policies motivate efficiency gains. The result is a lower energy/GDP ratio than has been observed historically. The fuel mix, however, gets more carbon intensive in the baseline scenario of many countries as the share of coal and oil increases by the year 2020. Some smaller countries, Ghana and Nepal for example, have CO_2/GDP elasticity well in excess of 1. The higher elasticity is a result of switching from biomass, which is assumed to have no net CO_2 emissions, to modern fuels like kerosene and LPG. India, South Korea, and China, which are among the three largest contributors to CO_2 emissions, have CO_2/GDP elasticities less than 1. In China's case, the fuel mix becomes marginally more carbon intensive, which is more than offset by an energy/GDP elasticity of 0.5. Future carbon emissions increase at annual rates of 3.6% for China, 4.9% for India, and 2.7% for South Korea compared with the much higher recent growth rates of 4.4%, 6.7%, and 10.3%, respectively.

Is it possible to reduce emissions beyond baseline scenarios, and how much would this cost? The studies show a potential to reduce emissions beyond the baseline scenario ranging from a low of 12% for South Korea to more than 50% for Brazil. Generally, the countries most endowed with natural energy resources have the largest potential for further reductions using renewable energy sources. Between one quarter to one third of the carbon emissions in the baseline scenarios in China and India could be reduced in the mitigation scenario in the target year (Table 2). Each study investigated dozens of individual options to improve energy efficiency and substitute fuels. The reduction amount for China in the ALGAS study in the year 2020 is as high as 430 MtC; for India it is around 330 MtC in the year 2025. The average cost of reducing emissions by this magnitude is negative for India because both energy efficiency improvement and fuel switching are cost effective, whereas it is positive for China and South Korea. This negative cost implies that, leaving aside barriers to market penetration and the transaction costs of overcoming them, it would be cost effective for India to pursue a carbon-friendly strategy as a baseline scenario. An important caveat here is that the extent of emissions reduction and the corresponding costs in the mitigation scenario are estimated relative to the baseline, whose definition is open to interpretation and judgement about a country's future. If reforms in India capture the full energy efficiency potential and fuel allocation is least-cost, then a mitigation scenario for India would also show positive cost.

Although the annualized or life-cycle cost may be negative for India, it would be difficult for the country to raise the necessary capital or hard currency to pay for renewable energy sources or imported natural gas. On the other hand, it may cost more for China and South Korea to reduce their emissions beyond the baseline scenario, but—as a proportion of GDP—the increased capital and hard currency requirements for these countries would still be modest and affordable.

Implementation of the mitigation scenarios in Brazil, China, and India (39) will lead to a reduction in the demand for oil by a small percentage in the target year but would substantially increase the demand for natural gas. The study scenarios suggest that natural gas demand in India, China, and Brazil in the mitigation scenario would amount to 15.9 mbpd compared with 10.7 mbpd in the year 2025 period (39). Additional demand from other countries pursuing mitigation would require much more natural gas than the 4.5 mbpd being traded today.

Are carbon taxes a feasible alternative for reducing emissions? Only a handful of studies have evaluated this question (for China, Egypt, India, Nigeria, and Venezuela); for each country, the GDP growth rate slows with carbon taxes. The Nigeria study shows, however, that the decline can be offset by improving productivity of energy use. The policy prescription would then be to implement initiatives to improve energy efficiency along with an increase in carbon taxes.

4. FORESTS

Developing countries account for 58% of the global forest area of 3.44 Gha; practically all tropical forests, which represent 52% of global forest area, are in developing countries (55, 56). In addition to being large carbon sinks, forests also contribute to CO_2 emissions; an estimated 1.6 ± 0.4 GtC is emitted annually from tropical forests (4). Deforestation in tropical countries is expected to continue in the next century, contributing to growing CO_2 emissions (57, 58). We focus primarily on activities that can reduce carbon emissions or sequester carbon in forests in developing countries.

Table 7 Examples of forestry sector mitigation options[a]

Categories of mitigation options	Examples of mitigation options
Forest carbon conservation measures	Banning deforestation or forest conversion to non-forest uses
	Protected areas—conversion of forests to national parks and sanctuaries
	Sustainable logging
	Forest fire control techniques
	Fuelwood conservation and substitution
	Fuel-efficient stoves
	Efficient charcoal kilns
	Biogas
	Recycling of forest products (paper)
Carbon storage management	Natural regeneration
	Reforestation in degraded forest lands
	Afforestation in non-forest lands
	Carbon pools in durable wood products
Substitution management	Bioenergy substituting fossil fuel electricity
	Sustainable wood products substituting fossil fuel based building materials (cement, steel, etc.)

[a]From Reference 3.

4.1 *Primary Mitigation Options*

Brown et al (56) identified three broad categories of forest mitigation options: carbon sink conservation and management; carbon storage management (expanding carbon sinks); and fossil-fuel carbon substitution management. Examples of mitigation options for each of these categories are listed in Table 7.

4.1.1 CARBON SINK CONSERVATION AND MANAGEMENT The annual rates of deforestation in developing countries between 1981 and 1990 were estimated to be 16.27 Mha, of which 15.41 Mha occurred in tropical forests in developing countries (55). The forest carbon sink conservation mitigation strategy involves halting or slowing deforestation and forest degradation through legislative bans on forest clearing, accompanied by measures to provide alternate sources of biomass (fuelwood and timber), alternate livelihoods for forest-dependent communities, and increased agricultural productivity (56). Other mitigation measures are creating protected areas; introducing sustainable logging; improving the efficiency of harvesting, processing, and use of forest products; and recycling of forest-wood–based products. Forest conservation and forest carbon sink conservation should be priority mitigation options for all tropical countries because, in addition to their CO_2 emissions reductions benefits, these strategies have significant implications for biodiversity conservation, watershed protection, and prevention of desertification and land degradation.

4.1.2 CARBON STORAGE MANAGEMENT Deforestation and degradation from over-extraction of fuelwood and timber, grazing, and fire lead to loss of carbon in vegetation and soil to atmosphere. Carbon sink management entails measures to increase carbon density in vegetation and soil in the existing degraded forests as well as measures to create new carbon sinks on non-forest lands or in areas where forests have been destroyed (59). These options include promotion of natural regeneration, reforestation, afforestation, and agroforestry. Carbon sequestration stops when a forest matures; thus, mitigation potential is finite. Carbon pools can also be created through production of durable wood products and by extension of the life of wood products through means such as timber treatment and the production of long-lasting particle board (60).

4.1.3 FOSSIL-FUEL CARBON SUBSTITUTION MANAGEMENT Substitution management views forest plantations as renewable resources (61) and has the largest long-run mitigation potential. Substitution management involves conversion of biomass into products that substitute for or reduce the use of fossil fuels. Measures include substituting bioenergy for fossil fuels or fossil-fuel electricity as well as replacing non-wood products that require fossil fuels for their manufacture (e.g. steel and cement) with sustainable wood products (56).

Under sustainably managed substitution options, perpetual carbon emission reductions could be achieved (61). Substituting biomass-fueled for coal-fueled electricity can avoid four times more carbon emissions than the amount of carbon that would be sequestered in plantations over a period of 100 years (62). Primary forests should be conserved for their contributions to biodiversity and watershed maintenance as well as for their role as carbon sinks. Degraded forest and non-forest land can be used for sustainable production of biomass for energy (63).

Short-rotation woody crops have the potential, with advances in energy conversion and yield, to reduce global fossil-fuel emissions by up to 20% (63a, 64, 65). A study in India has shown that biomass-based, decentralized, small-scale electricity systems could offset nearly a quarter of India's fossil-fuel emissions annually (63).

4.2 *Mitigation Options, Potentials, and Cost Effectiveness: Global Estimates*

Regional as well as global assessments of mitigation potential and costs suffer from limited data on socio-economic and political pressures on land available for mitigation, complex land use regulations, diverse ecosystem features (soil, water availability, species), matching land category to mitigation options, and wide variations in carbon uptake rates, as well as on costs of inputs.

4.2.1 LAND AREA SUITABLE FOR MITIGATION OPTIONS In developing countries, a significant part of deforestation results from demand for land for crop production. According to some estimates, humans have cleared more than 750 Mha of land in developing countries (66, 67) and more than 90% of this land is inefficiently managed and/or is used for marginal agriculture (68, 69). According to an IPCC assessment, 700 Mha are likely to be available globally for mitigation options (345 Mha for plantation forestry, 138 Mha for slowing tropical deforestation, and 217 Mha for natural and assisted regeneration) (56).

In tropical countries, according to Nilsson & Schopfhauser (70), actual availability (130 Mha) is only 6% or so of those lands deemed suitable (2228 Mha) because of cultural, social, and economic constraints (71). According to Bekkering (72), 483 Mha is suitable for reforestation in 11 tropical countries alone. In Asia, Africa, and Latin America, suitable land is estimated to be 251 Mha for forest plantation options, 1053 Mha for forest management, and 1895 Mha for agroforestry (66). According to Andrasko (73), out of the 865 Mha of land that is technically suitable for forest management in tropical countries, only 34% is "socio-politically" available. In India (63) and China (74) alone, total land suitable for mitigation is estimated to be 52 and 200 Mha, respectively. Looking at this range of estimates, we can conclude that IPCC-SAR (3) estimates of land suitable for mitigation in the tropical region are conservative.

4.2.2 MITIGATION POTENTIAL IN TROPICAL FOREST COUNTRIES The global mitigation potential for forest conservation (slowing deforestation), forestation, regeneration, and agroforestry options is estimated to be in the range of 60–87 GtC (Table 8) (56). The tropical forest region accounts for 45–72 GtC of this global mitigation potential. Mitigation potential in the tropical region, according to other estimates, ranges from 53 GtC (65a) to 167 GtC (66). In the tropics, there is large potential for mitigation through forestation (16.4 Gt), regeneration (11.5 to 28.7 Gt), slowing deforestation (10.8 to 20.8 Gt), and agroforestry (6.3 Gt). In China, which is included in the mid-latitudinal (temperate) zone, the potential for mitigation is estimated to be 1.7 Gt, which is a conservative estimate in view of the land area figures used.

4.2.3 COST OF MITIGATION AND INVESTMENT REQUIRED In the tropical region there is a wide variation in the investment cost for abatement of carbon, ranging from \$1 to \$29/tC abated (Table 8). The least-cost option is natural regeneration on the degraded forest lands, which costs in the range of \$1–\$2/tC. Forest

Table 8 Global carbon that can be sequestered and conserved and related costs (1995–2050)[a]

Latitudinal zone	Measure	Carbon sequestered (GtC)[b]	Cost (US$/tC)[c]	Total cost (10^9 US$)[d]
High	Forestation	2.4	8 (3–27)	17
Mid	Forestation	11.8	6 (1–29)	60
	Agroforestry	0.7	5	3
Low	Forestation	16.4	7 (3–26)	97
	Agroforestry	6.3	5 (2–12)	27
	Regeneration	11.5–28.7	2 (1–2)	
	Slowing Deforestation	10.8–20.8	2 (0.5–15)	44–97[e]
Total		60–87	3.7–4.6 (1–29)	250–300

[a]From Reference 3.
[b]Includes above- and below-ground vegetation, soil, and litter carbon. GtC, gigatonnes of carbon.
[c]Establishment or first cost (undiscounted). Average of estimates reported in the literature. Most estimates do not include land, infrastructure, protective fencing, education, and training costs. Figures in parenthesis indicate the range of cost estimates.
[d]Cost figures in column 4 are per tonnes of vegetation carbon. Total costs (column 5) are thus lower than the figure obtained by multiplying tonnes of carbon in column 3 by dollars per tonne of carbon in column 4.
[e]For slowing deforestation and enhancing regeneration combined.

conservation through reducing deforestation, according to an IPCC review of a large number of studies, is a cost-effective mitigation strategy; most studies reviewed report fewer than $3/tC conserved (56). The cost of mitigation through forestation varies depending on the type of forestation undertaken (eucalyptus plantations, teak plantations, community forestry, etc), the silvicultural practices adopted, and the cost of inputs. The investment cost for forestation options ranges from $3 to $26/tC abated in the tropical region. According to IPCC estimates, the total investment required for mitigation of 45–72 GtC in the tropical region would be $168–$220 billion (3).

Assessment of mitigation opportunities, potentials, and costs made for each country by national experts is likely to be more reliable than assessments by outside experts. Thus, the review in the next section is based on national mitigation analysis efforts.

4.3 *Mitigation Options, Potentials, and Cost Effectiveness in Selected Developing Countries*

This review of mitigation potential and cost effectiveness is based on studies conducted for the GEF-UNDP-ADB project (ALGAS) and US CSP, as well as a series of other studies (8; see also, for example, 74a). The majority of the studies have used the COMAP model (3) to assess mitigation potential and cost effectiveness parameters, and thus their outputs are comparable (see Section 4.3.1 for a description of the COMAP approach). The countries included in this review are Indonesia, South Korea, Mongolia, Myanmar, Pakistan, the Philippines, Thailand, Vietnam (42), China (42, 74), Cameroon and Ghana (74a), Mexico (74b), and India (74c). Data for a majority of the countries largely refers to 1997 prices except for India, China, Mexico, Cameroon, and Ghana, where generally 1994 prices are used. The exchange rate conversions predate the current East Asian financial crisis.

4.3.1 COMAP METHODOLOGY FOR FORESTRY MITIGATION STUDIES The key parameters in any forestry mitigation assessment are the (*a*) amount of carbon per unit area of land that can be conserved or sequestered in vegetation and soil under given set of conditions; (*b*) time period over which this carbon can be conserved or sequestered; (*c*) land available for mitigation projects; (*d*) costs of mitigation; and (*e*) different lifetimes of the wood products made from trees harvested at a site (56).

The COMAP (Comprehensive Mitigation Assessment Process) model (3) estimates the mitigation potential of options as well as their cost effectiveness parameters, such as unit abatement cost (investment as well as life-cycle cost per tonnes of carbon), NPV (net present value) of economic benefits per tonnes of carbon, and investment cost per hectare.

The COMAP model estimates the carbon implications of each category of mitigation option described in Section 4.1. For forest conservation, the methodology simply involves estimating, on a per-hectare basis, the CO_2 emissions avoided by halting deforestation or forest degradation (tonnes of carbon per hectare conserved). For plantations operated in rotation for an indefinite time period, assuming perpetual rotations, the model estimates the amount of carbon sequestered in vegetation as half the carbon sequestered by an individual plot that is stored indefinitely. The mitigation potential of substituting bioenergy for fossil fuel is estimated based on the quantity of fossil-fuel combustion avoided and the resulting carbon emissions (63). The COMAP model also estimates the carbon stored per hectare in decomposing matter, soil, and various wood products.

4.3.2 LAND CATEGORIES AND EXTENT OF LAND SUITABLE FOR MITIGATION Land availability for mitigation is a contentious issue because of peculiarities of land classifications, lack of data on extent of land available, legal disputes, and land regulations. Comparison studies from 13 countries (Table 9) showed that 74.8 Mha are suitable for natural (and assisted) regeneration, 191.5 Mha for plantation forestry, 179 Mha for agroforestry, and 66 Mha for slowing

Table 9 Land categories and extent of availability for mitigation in selected developing countries[a]

Country	Forest land for conservation, protection, and management (Mha)	Degraded forest land for regeneration (Mha)	Degraded land for plantation forestry (Mha)	Agroforestry (Mha)	Others (Mha)	Total geographic area (Mha)	Area under forests (Mha)
China		19.2	105.2	75.9		932.6	134.0
India		36.9	41.3	96.0		329.0	63.3
Indonesia			23.7			193.0	144.7
Mongolia		1.6	0.3			156.6	17.5
Myanmar	3.3	6.9				65.8	49.3
Pakistan	0.5	0.3	2.6	1.2		77.1	3.7
Philippines	6.6	2.5			0.60	29.8	6.5
South Korea	0.7	0.3			0.05	9.9	6.5
Thailand	17.8	4.4				51.1	14.0
Vietnam	10.5	2.7			2.50	32.5	19.0
Cameroon	1.6		7.3	1.6		46.0	36.0
Ghana	0.9		0.3	2.5		23.0	18.0
Mexico	24.7		10.8	1.9		196.0	117.0
Total	66.6	74.8	191.5	179.1	3.15	2142.8	629.5

[a]References: Cameroon and Ghana, 74a; Mexico, 74b; India, 74c; China, 74; other countries, 42.

deforestation. Thus, the global-level estimates of potential suitable land made by IPCC-SAR are conservative (see Section 4.2.1).

Larger developing countries such as China, India, and Indonesia appear to have larger area potentially suitable for mitigation (105; see 41 and 24 Mha for plantation forestry). Degraded land suitable for plantation forestry represents a significant percentage of total geographic area, which indicates how much land has been deforested (11% in China, 12% in India and Indonesia). India and China also have large agroforestry potential.

4.3.3 FOREST SECTOR CARBON EMISSIONS FROM LAND USE CHANGE Emissions inventories for the base year 1990 and projections for the year 2020 are given in Table 10. Emissions from forest sectors in China and Indonesia are negative (no net emission) for the base year 1990. The emissions from forest sectors are nearly offset by carbon uptake in regenerating forests and plantations in India, the Republic of Korea, Mongolia, Myanmar, and Pakistan. Significant emissions are estimated only for the Philippines, Mexico, and Thailand. Forestry sector emissions are projected to decline for the Philippines, Thailand, and Vietnam by the year 2020. Emissions are projected to increase in Pakistan and India.

Contrary to earlier studies, which projected large emissions for the forestry sector in tropical countries (75), the latest estimates using IPCC methodology are much lower or even negative for many countries. Differences in

Table 10 Carbon emissions from forestry and energy sectors during base year (1990) and projected emissions for 2020[a]

Country	Net national carbon emissions (MtC) (1990)	Carbon emission from energy sector and industrial processes (MtC) (1990)	Carbon emission from forestry sector		Total mitigation potential (MtC)	Ratio of mitigation potential of forestry sector to energy and industrial processes emissions of 1990 (in years)
			1990	2020		
China	506.1	572.1	−66.0	−105.0	9740	17
India	146.0	145.6	0.4	21.0	8753	60
Indonesia	−51.5	42.8	−94.3	−106.0	1745	41
Mongolia	5.2	3.8	1.4	−0.3	317	83
Myanmar	−1.6	0.9	−2.5	−1.4	582	647
Pakistan	20.0	18.0	2.0	19.0	161	9
Philippines	33.8	11.6	22.2	0.6	2380	205
South Korea	62.2	69.3	−7.1	—	119	2
Thailand	44.6	23.5	21.1	6.0	1259	54
Vietnam	19.9	11.4	8.5	−28.4	1480	—
Mexico	127.0	74.0	53.0	—	4115	—

[a]References: Mexico, 74b; India, 74c; China, 74; other countries, 42. MtC, Millions of tonnes of carbon.

methodology could explain the different estimates. IPCC methodology (which is being modified) includes carbon uptake for existing forests and plantations and for degraded as well as abandoned forests, unlike earlier methods that considered only emissions resulting from deforestation.

In addition, during the last 5–10 years, many countries have adopted strong measures to reduce deforestation along with large reforestation programs. In India, a strong Forest Conservation Act (1980), large afforestation programs implemented since 1980, and conversion of forests to protected areas have contributed to no net significant emissions from the forest sector (76). Similarly in China, since the period of 1977–1981, forested areas are increasing (77) because of large reforestation programs. Thus, the IPCC (4) estimate of 1.6 GtC for tropical deforestation could be high and may require revision.

4.3.4 MITIGATION OPTIONS POTENTIAL AND COSTS In this section, we assess mitigation options considered by different countries. Each country has considered a large number of mitigation options appropriate for its physical and biological features, precipitation, biomass demand, and land-use regulations. The categories of mitigation options selected and analyzed by the countries (Table 11) are plantation forestry, forest conservation and management, natural and assisted regeneration, agroforestry, and urban forestry and scattered trees in rural areas.

Table 11 Mitigation options, mitigation potential, and investment cost per tonne of carbon (tC) abated in selected countries[a]

Mitigation option	Mitigation potential (tC/ha)	Investment cost ($/tC)	Mitigation option	Mitigation potential (tC/ha)	Investment cost ($/tC)
China			India		
North and northwest			NR	62.0	1.5
Assisted NR	13.0	1.3	Enhanced NR	87.5	2.5
Plantation (pltn.)	55.0	1.3	AF	25.4	1.6
AF	15.0	16.3	CW	75.8	5.6
South, southwest, and northeast			SWF	80.1	7.3
Assisted NR	13.9	3.5	TF	120.6	3.3
Plantation	71.0	5.0			
AF	6.0	9.8			
Indonesia			S. Korea		
Timber estate	165.0	1.9	IMNF	99.4	6.0
SF	94.0	1.1	Urban forestry	299.0	9.2
Reforestation	214.0	0.9	ERL (*Larix leptolepsis*)	123.0	13.8
PF	99.0	2.1	ERP (*Pinus koraiensis*)	85.0	21.0
Afforestation	106.0	0.6			
Mongolia			Pakistan		
PF	99.2	0.8	Conifer forest–intensified FM		
NR	67.5	0.6	Protection	41.6	0.1
AF	9.8	0.8	Enhanced NR	33.8	8.8
Bioenergy	80	—	Reforestation	39.1	19.3
			Riverain forest pltn.	32.9	40.6
Shelter belt	101.7	0.9	Commercial pltn.	54.6	40.6
			Watershed mgmt.	26.7	34.8
			AF	29.7	1.6
			Pltn. on agric. land	7.5	0.7
			Rangeland mgmt.	20.0	17.4
Philippines			Thailand		
FP + sust. mgmt.	215.0	1.3	SR in CMF	185.5	2.5
FP (Total log ban)	215.0	0.5	SR in NPAS	158.9	2.9
Forest pltn.			LR in CMF	169.0	3.2
			MR in NPAS	112.5	4.3
Long	236.0	2.1	FP and Rf for conservation in PAS	38.6	7.5
Urban forestry	90.0	5.3	FP and Rf for conservation in CMF	38.1	10.7

(*Continued*)

Table 11 (*Continued*)

Mitigation option	Mitigation potential (tC/ha)	Investment cost ($/tC)	Mitigation option	Mitigation potential (tC/ha)	Investment cost ($/tC)
Vietnam			Mexico		
FP	106.9	0.1	NPA	30–170	
Degraded FP	64.3	0.2	Forest mgmt.	100–180	0.5–3.5
Enhanced NR	57.1	0.8	Restoration pltn.	70–80	7
Scattered trees	64.0	0.9	Pulpwood pltn.	70–100	5.5–7
Reforestation			Enhanced pltn.	167	
Short	43.0	2.2	AF	21	10–17
Long	68.2	1.7			
Ghana			Cameroon		
Evergreen forest			Evergreen forest		
AF	13–88	1–6	AF	16–58	1–5
Slowing deforestation	35–140	1–2	Slowing deforestation	40–160	1–2
Deciduous forest			Forestation	73–195	1–19
Slowing deforestation	35–140	1–2	Deciduous forest		
Forestation	31–154	1–27	Forestation	27–169	21–19
Savannah			Savannah		
AF	29–61	4–12	Forestation	36–170	1–31
Myanmar					
NR	33.0	0.1			
Rf-Long	155.0	0.8			
FP	47.0	1.6			
Rf-Short	55.0	3.8			
BE	78.0	21.4			

[a]ha, hectare; NR, Natural regeneration; AF, agroforestry; CW, community woodlot; SWF, softwood forestry; TF, timber forestry; SF, social forestry; PF, private forest; FM, forest management; FP, forest protection; NPA-natural protected area; References: Cameroon and Ghana, 74a; Mexico, 74b; India, 74c; China, 74; other countries, 42.

It is desirable to analyze mitigation options at the regional level, as studied for China (42, 74). Aside from China, all the remaining countries have used only one set of values for biomass productivity (or carbon uptake), costs, benefits, etc, for each mitigation option. These values vary from region to region even within a country. Even though slowing deforestation (forest conservation) is an effective mitigation option, some countries have not considered it. These include India (where deforestation has declined since 1980) (76), Mongolia (where forest land conversion to agriculture or infrastructure is minimal) (42), and Indonesia (where a large percentage of forest area can legally be felled or converted). Plantation forestry (afforestation and reforestation) and agroforestry options are considered by all the countries except the Republic of Korea, where the cost is high and little land is available for this purpose (42).

Mitigation potential Mitigation potential varies across countries and even within a country (74) for a given option (Table 11). Large mitigation potential is estimated for forest carbon sink conservation options such as forest management, forest protection, and slowing deforestation in Cameroon (40–160 tC/ha), in the Philippines (215 tC/ha), in Mexico (30–170 tC/ha), etc. Forestation or plantation forestry has a wide range of mitigation potentials, but in the majority of countries it is in the range of 70–100 tC/ha. Commercial plantations are estimated to provide even higher mitigation potential than forest conservation (165 tC/ha for timber estate in Indonesia, 120 tC/ha for timber forestry in India, 236 tC/ha for long rotation forestry in the Philippines). Agroforestry has a lower mitigation potential (6–15 tC/ha in China, 25 tC/ha in India, and 9.8 tC/ha in Mongolia) because trees will be planted with crops.

Cost effectiveness The investment cost (dollars per tonne of carbon) of mitigation is generally low for forest carbon sink conservation options ($0.1/tC in Vietnam and $1–$2/tC in Cameroon and Ghana) and plantation forestry options (in India, China, and Vietnam, $1.5–$5.6/tC abated) (Table 11). The mitigation cost is fewer than $2/tC for many mitigation options in Indonesia, the Philippines, Vietnam, and Mongolia. The cost of mitigation for different options is estimated to be high in the Republic of Korea, in Thailand, and for some intensively managed options in Pakistan (largely because of high labor and other input costs). The reported investment cost is fewer than $5/tC for mitigation options in most developing countries (other than Korea and for a few options in Thailand and Pakistan), which is lower than the values reported in IPCC-SAR (3, 78).

Cost benefit analysis showed that NPV of benefits are positive for majority of options in India (74c), Vietnam, Philippines, Pakistan, and Myanmar (42). This indicates that forestry sector options are profitable and are "no regret" options.

4.3.5 AGGREGATE MITIGATION POTENTIAL FOR FORESTRY SECTOR Country studies have adopted different scenarios to estimate aggregate mitigation potential and investment cost. We have focused on technical potential scenarios (which ignore market barriers and transaction costs) because all countries in our selection considered this type of scenario.

Cumulative mitigation potential Country studies show that, among the 13 countries in our sample, the largest mitigation potential is in China (9.7 GtC), followed by India (8.7 GtC), and Mexico (4.1 GtC) (Figure 1). The aggregate

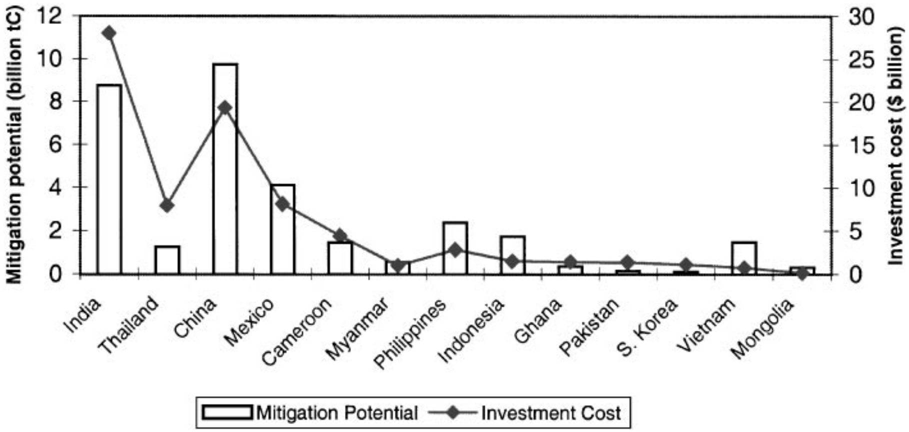

Figure 1 Forest sector mitigation potential and total investment cost for developing countries.

mitigation potential of the 13 countries is estimated to be 32 GtC. This aggregate potential shows that the IPCC-SAR assessment of mitigation potential for all tropical countries and China (45–72 GtC) is conservative (56).

Cumulative investment and unit abatement cost The cumulative investment required for the 13 countries is $77 billion, to realize a mitigation potential of 32 GtC, at an overall mitigation cost of $2.4/tC (Figure 1). India, Thailand, and China require an investment of more than $10 billion each for implementing technical potential scenarios.

Comparison of forest sector mitigation potential with energy sector emissions The ratio of forest sector mitigation potential (millions of tonnes of carbon) to carbon emissions from the energy sector (millions of tonnes of carbon per year) gives the potential of the forest sector to offset energy sector emissions, in terms of numbers of years (Table 10). When forest sector mitigation potential is compared with energy sector emissions for the base year (1990 in most cases), forest sector mitigation has the potential to offset energy emissions for periods ranging from 40 years in Indonesia to 647 years in Myanmar. The forest sector potential to offset energy emissions is insignificant for relatively developed Korea; it offsets energy emissions for only 17 years in China, where fossil-fuel emissions are high. In developing countries, the forest sector's potential to offset energy sector emissions is high for two reasons: Energy sector emissions are low, and there is large potential for slowing deforestation (because current rates are high) and reforestation (because of past deforestation).

5. IMPLEMENTATION OF MITIGATION OPTIONS IN DEVELOPING COUNTRIES

At the Third session of the Conference of the Parties to the UNFCCC in Kyoto, Japan, in December 1997 (3b), industrialized countries agreed to varying degrees of reduction to their 1990 base year emissions by the period 2008–2012. Developing countries, however, remained reluctant to commit to limiting the growth of their GHG emissions. This reluctance stems in part from their view that the industrialized countries are largely responsible for the historical emissions of GHGs and in part from concerns about how emissions limits may affect their prospects for economic growth. Global climate change, however, cannot be stabilized unless both industrialized and developing countries cooperate (13). Different solutions have been proposed, including letting developing countries (*a*) increase their GHG emissions or emissions per capita until they reach some future industrialized-country average (78, 79, 79a) and (*b*) increase emissions as industrialized countries decrease theirs until each country's contribution to atmospheric temperature increase is effectively equal, taking into account both past and future emissions (79b). None of the proposed approaches to joint responsibility for limiting GHG emissions has so far been accepted by governments signatory to the UNFCCC.

However, despite the political rhetoric and apparent reluctance, developing countries, for reasons other than climate change, are pursuing many energy and forestry programs and projects that are slowing their net GHG emissions growth. They have also reduced energy price subsidies. From 1990 to 1991 and 1995 to 1996, total fossil-fuel subsidies declined 45%, from $60 billion to approximately $33 billion in 14 developing countries that account for 25% of global carbon emissions from energy and industrial sources (80).

Our survey of mitigation studies highlights the fact that developing countries could pursue many additional, cost-effective GHG mitigation options in the energy and forestry sectors. Pursuit of these cost-effective options would reduce the rate of increase in carbon emissions from developing countries without jeopardizing, and in some cases enhancing, the countries' economic growth. Although the estimated GHG emissions reduction from a mitigation option depends on the baseline scenario that is somewhat subjectively defined for each country, experts from all the countries we have cited have nonetheless identified feasible negative-cost mitigation options.[4]

[4]Potential for negative-cost options is not unique to developing countries; a recent US Department of Energy study conducted by five national laboratories estimates a 7% reduction in GHG emissions is possible by 2010 at negative cost in the United States. This study considered both energy efficiency and renewable energy options, including nuclear power, and supports developing country contentions that industrialized countries should start reducing GHG emissions at home before seeking low-cost GHG mitigation projects outside their borders (5-lab study, 1997) (80a).

The mix of these options and their impact on emissions reduction differs across countries. Energy efficiency and renewable energy options that displace grid-connected electricity will not reduce emissions as much in Brazil, where electricity is largely generated using hydropower, as in China or India, where coal-based electricity generation predominates. Further, studies show a higher potential for renewable energy options in countries rich in natural resources. In the forestry sector, the studies identify large tracts of land that are suitable for forestation.

However, as we noted in Sections 3 and 4, many market barriers prevent adoption of cost-effective mitigation options in developing countries. In the energy sector, these barriers include the high first cost of equipment, a lack of information about new technologies, the presence of subsidies for electricity and fuels, and high tariffs on import of energy technologies. In the forestry sector, barriers include pressures on land availability for mitigation; absence of institutions to promote participation of local communities, farmers, and industry; risk of drought, fire, and pests; inadequate research and development capacity in countries; and poorly developed reforestation and sustainable forestry practices. Both sectors also suffer from an absence of appropriate methods and institutions to monitor and verify carbon flows (81).

In addition, implementation of GHG mitigation options involves many actors from the political, governmental, business/corporate, financial, institutional, environmental, and other sectors (84), who want their interests to be taken into account and who want to be adequately compensated for participating. A substantial body of literature discusses market barriers to the implementation of energy options (26, 82, 83), but not as much has been written about barriers to options in the forestry sector.

What conditions and policies are necessary to overcome these barriers and successfully implement GHG mitigation options in the developing countries? The combination of barriers and actors in each country creates a unique set of conditions, requiring customized implementation strategies for mitigation options. We highlight barriers and implementation strategies below, using illustrative examples, from three different viewpoints : macro or national, sector specific, and project specific.

5.1 *Macro Conditions*

Macro conditions relate to the entire socioeconomic structure of a country, particularly investments in which energy and forestry options are ignored, undervalued, or considered too risky by economic actors. Examples of macro barriers include (*a*) a low level of competition among firms resulting from regulation of the domestic market and/or from policies that constrain entry of imported products and impose high tariffs on imported goods and (*b*) a low level of capital market development.

For instance, government regulations prohibiting foreign firms from bidding on the construction of new industrial factories or power plants limits a country's access to new foreign technology. Conditions that constrain the entry of imported products can lead to the use of obsolete technology. The history of government intervention to address a severe paper shortage in India during the early 1970s illustrates this problem. To address the shortage, the Indian government promoted the establishment of small paper mills that could be quickly set up (85). This led to the import of inexpensive second-hand paper mills that were set up in many regions of the country. The inefficient mills grew to account for 50% of the country's paper production. Then, in 1988, the government removed the protection it had accorded the paper industry, which led to the shutdown of many of these small, inefficient plants. This elimination of government protection will, in the long run, increase energy efficiency.

Another example of the limitations created by government regulation was a high import duty imposed on CFLs in Pakistan. When this duty was reduced from 125% to 25% in 1990, the price of CFLs dropped by almost half, and sales started to rise, leading to improved energy efficiency (86).

Capital for investment from domestic sources is scarce in many developing countries, particularly where foreign exchange is required (see Section 3.1.5 for future scenarios). This monetary limitation affects the adoption of GHG mitigation options. In western India, for example, generating power with imported natural gas or naphtha is less expensive and emits less CO_2 than coal use emits; however, the hard currency needed to pay for imported gas requires that its use be carefully monitored, and government permission be sought for gas import.

5.2 *Sector Conditions*

There are several energy-sector and forestry-sector specific barriers to the implementation of mitigation options in developing countries. These include subsidized pricing of fuel, electricity, and other products; government policies regulating energy- and forestry-related activities; reduced government budgets and financing for energy and forestry projects; weakness in a country's institutional and legal framework; the uncertain status of private firms in the energy and forestry sectors; lack of information on mitigation options; and limited access to financing.

Rationalization of electricity and fuel prices is a key feature of reforms being carried out in many developing countries, where subsidies for LPG and kerosene are being reduced or removed, and electricity tariffs are being adjusted to reflect the cost of production. Fuel subsidies have been reduced or removed in India, Pakistan, Thailand, Brazil, and Mexico, to name a few countries.

There is great potential to reduce GHG emissions by substituting bioenergy for fossil fuels. Often, bioenergy may have to compete with subsidized fossil fuels and fossil-fuel–based electricity. For example, electricity for pumping irrigation water (a major electricity-using activity) in rural areas of India is supplied free or at a highly subsidized rate. For bioelectricity to compete with fossil-fuel electricity in this situation, it may be necessary to adopt rational electricity pricing for fossil-fuel electricity (3, 61, 63).

Many financial, administrative, and policy reforms are necessary to promote forestry measures to reduce GHGs and to enhance carbon sinks (87). Strong forest policies are required to regulate or ban forest clearing. India, for example, enacted a Forest Conservation Act in 1980 that regulates all conversion of forest land to non-forest uses. This policy has significantly reduced deforestation rates (76). Vietnam is in the process of enacting a policy to regulate extraction from forests for export. Brazil issued a decree (No. 151) suspending the granting of fiscal incentives to new ranching projects in Amazon forest area, in order to decrease the rate at which the forest is cleared (87).

Forest-based industries in many countries often obtain large concessions from the government forest department for extracting timber from forests for which they pay low royalty charges (88). There is a need for withdrawal of such subsidies (89). In addition to eliminating subsidies, efforts are needed in order to prevent timber harvest from natural forests by persuading forestry firms to acquire raw materials from non-forest areas such as farm lands or degraded lands. Financial incentives could be provided to enterprises that source wood from non-forest lands. Farmers could be provided with seedling material, low-cost credit, and an assured market and price to encourage farm forestry programs for supplying wood to the industry. An interesting development in India along these lines has been the recent planting of teak by private entrepreneurs, with capital raised in private capital markets. There are also examples of paper mills in India that provide credit and seedlings and enter into agreements with farmers to purchase eucalyptus wood at harvest (63).

Government budgets are stretched tight as the energy sector expands faster than economic growth and the government budget is inadequate to finance new power, natural gas and petroleum, and renewable energy projects. Deregulation to allow private producers into an area that hitherto has been dominated by government-owned companies is one solution to this problem. The governments of Argentina, Chile, and Brazil have privatized the generation and supply of electricity and fuels. On the other hand, in Asian countries the trend has been toward keeping government-owned companies but allowing private energy suppliers to operate in parallel.

The development of companies that could provide energy services that reduce GHG emissions growth can be limited in countries where there is no existing legal framework for contracts with energy service companies (ESCOs), such as in China. Although ESCOs are being formed in many countries, their status is often uncertain; the prices they will be paid for saving electricity are being negotiated on a utility-by-utility basis, for example, in India.

Analysts and governments are not fully aware of the variety of mitigation options that can be pursued in a sector. The bilateral programs, such as the US CSP or the German and Dutch programs, were created, in part, to fill this need by training analysts and providing information to developing-country governments about the consequences of pursuing mitigation options. The programs have trained hundreds of experts in developing and transition countries on mitigation methods and analytical techniques (90).

5.3 *Project Conditions*

Most of the climate change projects in developing countries are being funded by foreign investors under the activities implemented jointly (AIJ)/joint implementation (JI) concept. AIJ/JI allows for full or partial financial support from an investor country, which receives credits for some of the GHG emissions reduced by projects it undertakes in a recipient country. These credits are used toward the investor country's emissions-reduction commitment under the UNFCCC. Several concerns have been voiced regarding AIJ/JI projects. These include the transfer of high cost and/or obsolete technology, negative local impacts, additionality of funds and carbon emissions reduction, lack of capability to monitor carbon flows of projects, sharing of carbon credits, and macroeconomic impacts.

A recent study of current and proposed energy, forestry, and bioenergy projects in Brazil, India, Mexico, and South Africa shows that most of these concerns are unfounded. The review of projects showed that these are or will contribute to rural employment, reduce air pollutants in addition to GHGs, increase manufacturing capacity, conserve biodiversity, reclaim degraded lands, and protect watersheds (91). The additionality of funding, however, could not be assured under the reviewed projects, and the equitable sharing of carbon credits remained a concern.

The macroeconomic benefits of these projects were also positive because they provided new jobs and reduced oil and timber imports. Another study of impacts of mitigation options for India showed significant positive impacts on economic output from forests, as well as a threefold increase in the contribution of the forestry sector to GDP, a large increase in employment, and a net contribution to foreign exchange earnings (89). These energy and forestry studies clearly show that there need not be any conflict between the global benefits and the local or national socioeconomic and environmental benefits for climate mitigation projects.

One of the features of forestry mitigation projects is the long period before carbon mitigation is realized, which makes it necessary to ensure long-term community rights to control land and forest products (63, 89). Strong local institutions with legal backing are necessary to enable communities to participate in forestry programs over the long term (92).

5.3.1 INTERNATIONAL EFFORTS During the early 1990s, investors in industrialized countries began setting up carbon emissions offset projects in developing countries. These projects led to the inclusion of the concept of emissions reduction sharing, called joint implementation (JI), in Article 4.2 of the United Nations Framework Convention on Climate Change (FCCC). JI is designed to encourage global emissions reductions by overcoming financial barriers to projects. The Kyoto Protocol to the FCCC, put forth in December, 1997, modifies the JI concept and provides for project-based climate change mitigation and emissions trading among industrialized (Annex I) countries. It also creates the Clean Development Mechanism (CDM) as a clearinghouse for certifying and possibly funding project-based mitigation in developing (non-Annex I) countries. The CDM's form has yet to be determined; however, projects that might be pursued under CDM are likely to face the same technical and political issues and concerns as those being voiced today under the JI/AIJ regime.

The Global Environment Facility (GEF) jointly administered by the UNDP, the UNEP, and the World Bank is another means of addressing financial barriers to mitigation projects. The GEF provides funds for projects in order to encourage their implementation or to subsidize projects that would not otherwise be cost effective. GEF funds are limited; their main purpose is to demonstrate the feasibility of climate change mitigation projects.

6. CONCLUSIONS

Climate change impacts can be mitigated through energy efficiency and fossil-fuel substitution options in the energy sector, and through management of forests for carbon conservation, expansion, and fossil-fuel substitution. Studies of these options in dozens of developing countries have identified a significant potential for reducing future carbon emissions. These studies also show that a sizable subset of the options identified for each country are cost effective and produce benefits such that they merit implementation even without regard for their carbon emissions reduction benefits.

Many developing countries have already successfully pursued such options, reducing the growth of their energy demand and consequent carbon emissions. For example, primary energy demand in China has increased at half the economic growth rate since 1980, in part because of a strong administrative carrot-and-stick program that rewards firms that achieve stipulated norms for energy use/output and removes or reduces fuel and electricity subsidies to those that do not meet the standards (17, 21). Other countries, including Brazil (93), Mexico, and Thailand, have pursued similar but more targeted programs to improve energy efficiency and introduce renewable energy technologies less successfully.

In the forest sector, developing countries have realized the need for forest conservation and revegetation of degraded forest lands for reasons other than carbon mitigation. Countries such as India, Brazil, Indonesia, Thailand, China, and Vietnam have adopted forest conservation policies (4) as a result of strong forest conservation legislation coupled with large social forestry programs. In China, forested areas increased from 115 Mha in a 1977–1981 inventory to 134 Mha during the 1989–1993 inventory period.

Studies show that GHG mitigation projects that have been jointly implemented, or designed, thus far under the UNFCCC benefit local communities and host countries. Such projects should be pursued aggressively under the Clean Development Mechanism (CDM) proposed for the Kyoto protocol. However, monitoring and verification of the carbon benefits of such projects, and the acceptance of emissions caps on national emissions, are necessary to encourage large-scale implementation of climate mitigation projects under the CDM.

The mitigation studies we have reviewed show that many more cost-effective GHG mitigation options could be pursued in developing countries. Top-down analytical studies also illustrate that a combination of shifting investment from increasing energy supply to efficiency improvements and tax policies could increase GDP, aiding each country's prospects for economic growth. Mitigation options face many barriers at the macro, sector, and project levels. Removal of these barriers will improve developing countries' access to financing and advanced technologies, both of which are perennial concerns for developing country governments. Policy reforms to encourage environmental sustainability, increased productivity, improved infrastructure and planning, and carbon-project monitoring are essential for large-scale implementation of mitigation options. A large national and international financial commitment is also necessary (61).

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